Chapter 2 | HVAC in the Southwestern Climate Region

INTRODUCTION

HVAC AT-A-GLANCE

Heating, ventilation, and air conditioning (HVAC) are the equipment and systems that control the conditions and distribution of indoor air. Indoor air must be comfortable, healthy, and safe. HVAC systems address these needs by controlling indoor temperature and relative humidity (RH), and by filtering air and providing ventilation air to improve air quality. HVAC systems also control ancillary effects such as building pressure and direction of airflow, which can affect the growth of mold inside a building and can impact the correct operation and venting of combustion equipment. Installing efficient HVAC equipment, scheduling and operating it in optimum fashion, and maintaining the systems and controls will achieve a comfortable and healthy indoor environment in an energy-efficient manner. ASHRAE Standard 180-2008 "Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems" provides guidance regarding inspection and maintenance practices for HVAC systems.

Heating, ventilating, and air conditioning maintenance practices have a significant effect on a building's energy use and the comfort of its occupants. HVAC systems are typically the largest users of energy in most buildings—about 45% of a typical office building's energy use, compared with about 23% for lighting and 32% for internal equipment.

This chapter discusses operation and maintenance practices of common types of HVAC equipment employed in the common (non-residential) spaces of public housing authority (PHA) buildings in the southwestern United States. Common spaces include offices, meeting rooms, laundry rooms, and community gathering areas. The size and arrangement of common areas within public housing buildings varies significantly from one PHA site to another. They range from small single-zone detached buildings to large multi-story buildings with common space areas distributed throughout the building. These spaces may be served by a variety of HVAC systems.

Public housing office and common space may be designed and operated so that occupants cannot meet individual comfort needs through access to operable windows for ventilation and thermostats to adjust temperature. Sometimes the cooling and heating system strictly maintains a "comfort zone" without regard to whether or not occupants feel hot or cold, or even if anyone is present. Complaints that areas are too hot or too cold can plague facility managers. These factors point to the difficult tasks that the building HVAC engineer and the maintenance staff must carry out in order to balance occupant comfort with building and equipment efficiency, while keeping maintenance costs low. It is a challenging task because comfort problems that affect employee productivity may outweigh the cost of cooling, heating, or ventilating the building.

After discussing maintenance considerations and regional climate demands, this chapter summarizes operation and maintenance practices of specific HVAC equipment used in public housing. Due to the wide variety of building types and of common spaces found in PHAs, the information is organized by primary type of equipment. Within each section, a discussion with some tips for improved HVAC operation is followed by maintenance guidance or a checklist. Later sections in this chapter cover recommendations on how to limit energy consumption from devices brought in by employees, and issues to consider when planning equipment replacement or upgrades.

Maintenance Considerations

A good maintenance program maximizes equipment performance and life expectancy in the most cost-effective manner. Good communication between people familiar with the equipment and with management will help to establish realistic budgets. There are generally three ways to consider maintenance: Reactive, Preventative, and Predictive.

REACTIVE MAINTENANCE is the practice of repairing or replacing equipment only after operation is impaired or has ceased. Also referred to as "run-to-failure," this practice can diminish HVAC performance, resulting in more complaints about comfort and reduced air quality control. Waiting until total equipment failure can also cause additional component damage and higher costs, especially if the repairs must be made when emergency or overtime rates apply.

PREVENTATIVE MAINTENANCE is performed according to a schedule or based on actual equipment operation runtime. While more efficient than reactive maintenance, preventative maintenance may also result in inefficiencies. For example, an air filter is often changed according to a calendar schedule, but this type of activity may actually “waste” some of the useful life of the filter.

PREDICTIVE MAINTENANCE is based on the actual condition of equipment, but it goes further than preventative maintenance. Predictive maintenance tracks fault frequency and costs, and uses this information to predict when maintenance should be implemented. While upfront costs to start and maintain a predictive maintenance program can be high, the U.S. Department of Energy (DOE) Federal Energy Management Program (FEMP) claims this is a very cost-effective approach that yields savings that are ten times the cost of a predictive maintenance program. This program should also provide energy savings of 8–12%, reduced maintenance costs of 25–30%, reduction in breakdowns by 70–75%, and reduction in downtime by 35–45%.

The HVAC maintenance team must balance system efficiency and occupancy comfort, which at times seems incompatible. This balance may be achieved by considering the following, arranged from a broad to narrow focus:

- **HUMAN FACTORS:** Focusing on individuals’ comfort zones instead of maintaining buildings at prescribed conditions may achieve both energy efficiency and occupant comfort.
    - Operate space conditioning and ventilation systems for occupant comfort during work periods.
    - Establish a policy of providing conditions within a range that occupants can depend on so they can adjust clothing as needed. For instance, those for whom an air conditioning setpoint of 75°F is too cold can plan to wear long sleeves. Consider ASHRAE Comfort Standard 55 for guidance.
    - Allow occupants to self-regulate temperature within a predetermined range through better access to supply vents and thermostats.
- **LOCATION, TEMPERATURE, AND LOAD FACTORS:** Focus on providing temperature for spaces according to their function. Where possible, reduce HVAC loads by establishing temperature setpoints for different spaces (e.g., hallways can be cooler in the winter and warmer in the summer than office areas).
- **EXTERNAL FACTORS:** Occupant comfort is often affected by factors such as leaky or low-performance windows, heat gain or loss through poorly insulated walls, and thermal stratification within the space. Energy savings can be achieved through building envelope improvements such as reflective window blinds, exterior shading of walls and windows, and improved thermal performance of windows and walls.

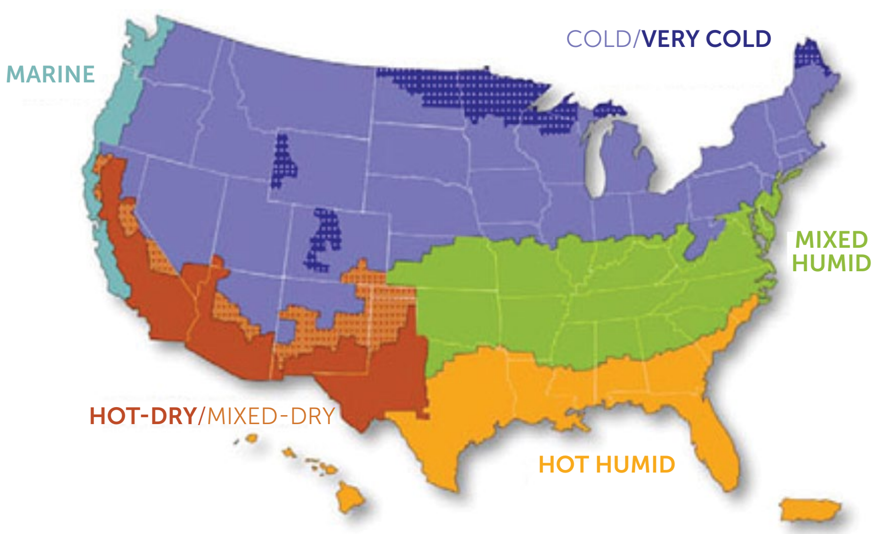
- **LOW-COST OR NO-COST SYSTEM MODIFICATIONS:** In addition to operation and maintenance practices, a number of relatively low-cost or no-cost, quick-return measures can reduce energy consumption. They include sealing ductwork, adjusting thermostat settings, improving operating procedures, and automating system controls. Consider, for example, that raising cooling setpoints can reduce cooling energy consumption by about 8% per degree change, while lowering heating setpoints can reduce heating energy consumption by about 4% per degree change, depending upon the climate zone.

Regional Climate Demands

This chapter addresses the southwestern climate zone, which consists of the hot/dry and mixed/dry portions of the United States, including portions of Texas, New Mexico, Colorado, Arizona, Nevada, and California (Figure 1). This climate zone generally has hot summers and a mild-to-moderate heating season. Throughout most of this climate zone, cooling is dominant for about four to five months. Some coastal areas along the southern California coast experience cool summers and warm winters, with relatively little temperature variation from month to month. Cooling degree days (CDDs) vary widely from less than 1,000 to more than 4,000 within this climate zone. Heating degree days (HDDs) vary from about 1,000 to 3,000 (see Box 1). Throughout this region, the climate is dry with relatively little rain and low outdoor RH and dew point temperatures. The guidance provided in this manual will cover both cooling and heating issues for these dry climates.

Throughout most of the Southwest, summer days commonly have large temperature swings from night to day. Low outdoor relative humidity allows the nights to cool substantially and clear sunny days allow rapid heating. Sparse vegetation also contributes to rapid heating during the day. Daily temperature swings of 30oF to 40oF are common throughout much of this region, except along the Pacific coast. With abundant sunshine and clear sky at night, buildings in the Southwest will warm considerably during the daytime and cool down more at night than other regions. Proper shading of windows and/

FIGURE 1. DOMINANT U.S. CLIMATE REGIONS



or installation of high performance windows are key elements of both comfort and energy efficiency in buildings in this region.

High mass construction (such as thick masonry walls) can allow operation of space cooling systems during cool nighttime hours to sub-cool the building mass and consequently reduce AC operation hours during the hottest periods of the day. During some portions of the year, it may be possible to ventilate the building at night to store coolness in the building mass. In some areas of the Southwest where outdoor dew point temperatures are consistently low, direct evaporative cooling systems ("swamp" coolers) may be used to meet the majority of the space cooling loads. There may, however, be some periods of elevated humidity (such as the July "monsoon" season in Arizona) where outdoor dew point temperatures will be elevated and indoor temperature and humidity may rise above desired levels. These direct evaporative cooling systems are common in residences but less so in commercial buildings.

The heating season generally begins in October or November and ends in March or April, depending in part upon altitude. Some of the population centers in the Southwest are at 2000 ft or higher elevation, which contributes to a longer and colder winter. High mass construction is also useful during the heating season. Moderate daytime temperatures are followed by cold nighttime temperatures. Sunlight shining on the building exterior and through windows can introduce considerable heat during daylight hours. A massive structure can be useful in soaking up this excess heat, preventing overheating during the day, and reducing the need for space heating at night. With high mass, south-facing windows can admit considerable solar heat to the space without creating overheating and occupant comfort problems. With proper shading, the high-angle summer sun is kept out of south-facing windows while the low-angle winter sun is allowed to enter the space.

Low indoor humidity can be a problem in this region. While people give off moisture through perspiration and respiration, ventilation and infiltration

BOX 1. HEATING DEGREE DAYS AND COOLING DEGREE DAYS

Heating degree days (HDDs) and cooling degree days (CDDs) are useful tools to understand the amount of heating and cooling required for a specific climate.

HDDs and CDDs are defined relative to a base temperature: the outside temperature at which a building needs neither heating nor cooling. In most cases, the base temperature is 65°F.

Two examples show how HDDs and CDDs are calculated. Consider a summer day in Las Vegas where the average temperature over a 24-hour period is 90°F. To obtain CDDs, subtract 65°F from 90°F to yield 25 CDDs for that day. Consider a winter day in Las Vegas where the average temperature over that 24-hour period is 40°F. To obtain HDDs, subtract 40°F from 65°F to yield 25 HDDs for that day.

Following are HDDs and CDDs for various cities in the southwestern climate zone based on weather from the period 1971–2000.

	HDDs	CDDs	Elevation (ft)
El Paso	2543	2254	3934
Phoenix	1125	4189	1122
Las Vegas	2239	3214	2198
San Diego	1063	866	16
Los Angeles	1274	679	115
Sacramento	2666	1248	26
Redding	2961	1741	495

introduce low humidity air into the space. RH below 35% can lead to problems with static electricity that can affect electronic equipment. It can dry out skin and mucous membranes, leading to chapped lips, dry skin, and sore throats. To avoid low humidity, ventilation rates should be carefully adjusted. In some cases, humidification may be required. Alternatively, energy recovery ventilators (ERVs) can be used to capture humidity from exhaust air and deliver it into the incoming ventilation air stream.

OPERATIONS AND MAINTENANCE PRACTICES

This section covers the operations and maintenance of the following equipment:

Cooling Systems	Condenser Units, Chillers, Cooling Towers
Heating Systems	Electric Resistance; Heat Pumps; Gas Furnaces; Central Steam, Hot Water, and Radiator Space Heating Systems
Air Distribution Systems	
Air Handler Units	
Ventilation	
Comfort Controls	Thermostats and Ventilation Sensors

HVAC maintenance practices vary depending on the type of equipment, building, and existing envelope measures, as well as building location, size, use pattern, and purpose. Thus, it is impossible to identify specific maintenance practices that fit all circumstances. Rather, use the following guidelines to develop a combination of practices and schedules that will best serve the occupants' needs, maintain good indoor air quality, reduce energy consumption, and lessen environmental impacts.

An energy audit is highly recommended as an initial step to improve energy efficiency. Various levels of audits, from preliminary to comprehensive, can be obtained from energy service companies, architecture and engineering firms, or utilities. (Note to government facility managers: The Federal Energy Management Program (FEMP) can also provide this technical support on a reimbursable sub-contract basis).

Cooling Systems

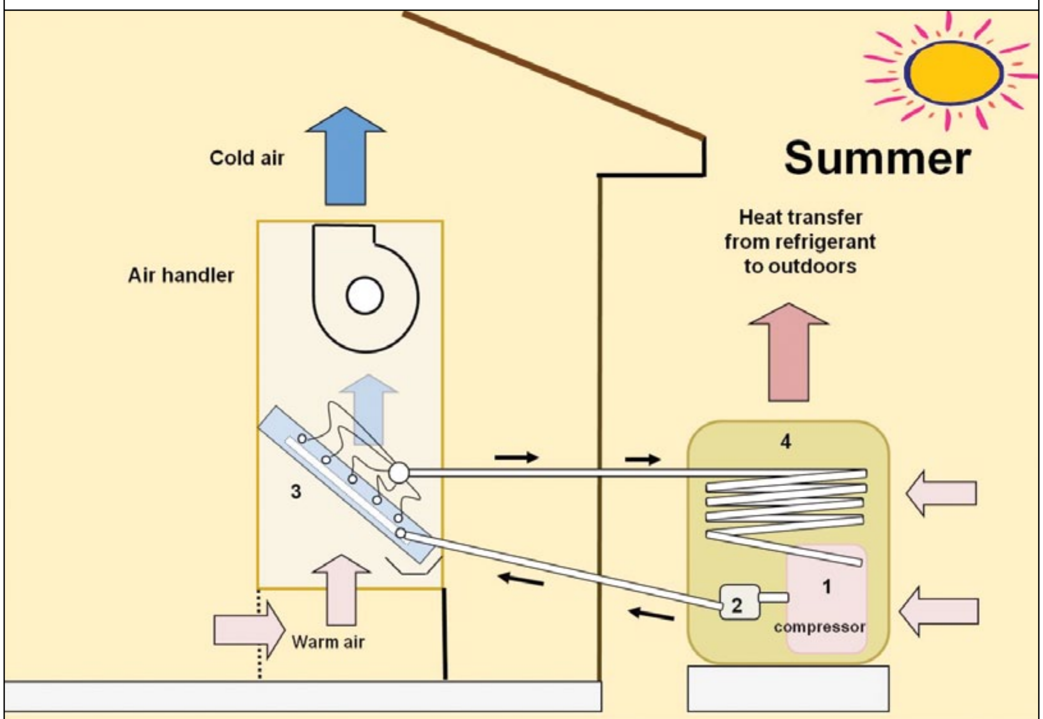
The cooling systems primarily used in southwestern public housing can generally be classified as direct expansion or chilled water systems. Most are direct expansion systems that require an outdoor condenser unit to exchange heat to the outdoor air. The condenser unit will be discussed here and the indoor air heat exchange of this system will be discussed in the Air Distribution System section. While not as common, some multi-story public housing buildings use chilled water systems.

Condenser Unit Operation

Air conditioners that use direct expansion (DX) cooling circulate refrigerant in a circuit between two heat exchange surfaces (see Figure 2). The process begins with pressurized refrigerant at the compressor (#1 in the figure) that is transferred through an expansion valve (#2) before entering the evaporator coil (#3). The evaporator is located inside the AHU where a fan blows air through it to pick up cooling. The refrigerant then travels back to the condenser unit (#4) located outdoors. Refrigerant gives up heat to outdoors, then the cycle begins again.

FIGURE 2. HEAT EXCHANGE IN A DIRECT EXPANSION SYSTEM IN SUMMER

1) compressor 2) expansion valve 3) evaporator 4) condenser



All illustrations and photographs in this chapter are courtesy of Jim Cummings and Charles Withers, unless otherwise noted.

Service technician using sensor to locate refrigerant leak around condenser coil.

Mirror and dye used to locate leak.

The condenser unit (or outdoor unit) contains the compressor, condenser, a fan that moves air across the condenser coil, and electronic components. Because this equipment is outdoors, it can become dirty and will be exposed to corrosive environmental factors over time. Heat transfer relies upon the coil surfaces remaining fairly clean. Therefore, the condenser coil must be protected from anything that interferes with airflow around and through it.

CONDENSER UNIT MAINTENANCE GUIDANCE

Maintenance	Description
	Annually
Outdoor coil	Clean the outdoor coil and remove any debris such as leaves or dirt from around or near the outdoor unit. Repair damaged fins. Place protective cover over top of unit at the end of cooling season if it is located under a roof edge where ice can fall onto it during winter.
Refrigerant leaks	Inspect tubes and coil for evidence of leaks. Have a leak test done and seal leak on system that requires refrigerant to be added.
Fan	Lubricate fan motor bearings according to manufacturer's recommendation. Inspect fan for damage or unusual vibration or noise. Tighten and adjust fan mounts as needed.
Electric power	Inspect wiring and electric connections. Tighten loose wires and replace weathered or nicked wiring. Measure heat pump amperage under operation and verify it is within manufacturer's specifications. Repair or replace equipment operating outside specifications.

Chiller Operation

A chiller uses a refrigeration process to cool water that is transported into the building to provide space cooling. How the chillers are operated and the method used to "condition" water significantly affects operating efficiency. Historically, chillers have worked most efficiently when operating at full-load rather than part-load. Buildings, however, produce full-load only a fraction of the time. In recent years, a new generation of variable-speed, variable-capacity chillers have entered the marketplace. Some of these units operate with magnetic bearings, allowing very high-speed, variable-capacity operation with very low noise and very high efficiency at part-load (as low as 320 Watts per ton at 40% load factor).

A chiller operates with two water loops. One loop takes water through the evaporator, which lowers the temperature of the chilled water. The other loop takes water through the condenser, which discharges waste heat to ambient air. A number of measures can increase chiller efficiency:

- **LOWER ENTERING CONDENSER WATER TEMPERATURES** will yield higher chiller efficiency. Decrease condenser water temperature by running it through a cooling tower. Operate the chilled water system to provide a relatively large temperature difference (of water delivered to the evaporator) from supply to return: Return water should be 15°F warmer than the supply water. If this differential drops to 10° or even 5°, the system efficiency will decline substantially. Careful balancing of the chilled water system flow rates through the various AHUs is important to maintaining the desired supply-to-return temperature differential. Replacement of standard chilled water valves with pressure independent valves can be a very cost-effective means to achieve and maintain balanced chilled water flow and the target 15°F temperature differential.

- **VARIABLE FREQUENCY DRIVES** (VFDs) vary the flow rate of chilled water through the building loop. This can save substantial pump energy use and help to achieve the 15°F temperature differential. During colder weather, water can be taken directly from the cooling tower to feed the chilled water loop and thus provide "free cooling" without the use of the chiller.
- **A SIMPLE AND ECONOMICAL CHILLER PLANT CONTROL NETWORK** for the chillers, pumps, and tower fans that automatically operates and sequences all equipment is a cost-effective way to optimize the energy efficiency of large complex systems. Designing and implementing such a network can save $20 to $100 per installed ton per year.

The table on the following page provides guidance on important chiller maintenance practices that should occur at least annually in early spring in preparation for cooling season.

CHILLER MAINTENANCE GUIDANCE

Maintenance	Description
	Follow Manufacturer's Recommended Schedule or At Least Annually
Evaporator and condenser	Clean the evaporator and condenser. Indications that cleaning is needed include poor water quality, excessive fouling, and age of chiller. Eddy current testing may be done to assess tube condition.
Refrigerant level and condition	Add refrigerant as required. Record amounts and address leakage issues.
Compressor oil system	Conduct analysis on oil and filter and change as needed. Check oil pump and seals, oil heater and thermostat, and strainers, valves, and any other significant components.
Compressor motor	Check all alignments to specification. Check all seals and provide lubrication where necessary. Consider vibration analysis. Check temperature per manufacturer's specification.
Motor load limit control	Check settings per manufacturer's specification.
Electrical connections	Check all electrical connections and terminals for contact and tightness.
Control functions	Verify proper control functions including hot gas bypass and liquid injection.
Compressor leak testing	Conduct leak testing on all compressor fittings, oil pump joints and fittings, and relief valves.
Insulation	Check for damaged or missing areas. Remove wet insulation and replace after surface is dry.
Chilled water reset	Check reset settings per manufacturer's specification.
Water	Assess proper water flow in evaporator and condenser. Test and inspect water quality to verify no biological fouling and make adjustments as needed. Test for appropriate levels of additives to water, such as glycol, if they are used.

Cooling Tower Operations

Cooling towers transfer heat from the condenser to the atmosphere using evaporative cooling. Their primary maintenance issues are scaling, corrosion, and biological growth that reduce heat transfer capacity and contribute to system "fouling."

Following are practices for more efficient cooling tower operations:

- **LOWER THE COOLING TOWER DISCHARGE TEMPERATURE** to the lowest manufacturer recommended setting.
- **IMPLEMENT A CONDENSER DISCHARGE TEMPERATURE RESET** to help optimize tower operation based on outdoor conditions. When using this method, the operator should set a cooling tower leaving temperature set-point at least 5°F above the ambient wet-bulb temperature.
- **CLOSE THE BYPASS VALVE BEFORE STARTING THE COOLING-TOWER FANS** to avoid short-circuiting of hot water returning directly back to the chiller, which would lower chiller efficiency.

- **USE THE TREND-LOGGING CAPABILITY OF THE DIRECT DIGITAL CONTROL (DDC)** to track the temperature of the water leaving the tower. Higher than normal temperatures may indicate that the tower is not operating properly.

Cooling towers create environments conducive to biological growth. Pathogenic organisms such as *Legionella Pneumophila* (Legionnaires' disease) can develop in circumstances where the water is warm (95–99°F) and has a high concentration of minerals. Although awareness of this issue has helped reduce the incidence of sickness from cooling towers, **locating outdoor air intake vents far from the cooling tower plumes is critical to avoid entrainment of these pathogens into ventilation air.**

The most common treatments for scaling, corrosion, and biological/bacterial growth are the use of chemical additives and significant over-use of water. Most system operators use chemical biocides to inhibit biological growth, and allow a significant amount of "blow down" or deliberate water overflow to introduce fresh water into the system, thereby reducing the concentration of contaminants and the buildup of scale. These water treatment practices, however, can have significant impacts on the environment and should be considered and implemented carefully.

Blow down helps clean the tower, but should be limited since it requires more make-up water. In addition, spillage transports chemicals, such as chlorides, chromates, corrosion inhibitors, high concentrations of sulfides (if the water is treated for pH), and elevated concentrations of salt, into the external environment.

There are a number of alternative options to chemical treatment of water; however, they tend to require additional investments in the chilled water system. **Ozone treatment and mechanical cleaning are two viable alternatives to the use of chemical biocides.** Both have advantages and disadvantages, and both can have high initial costs. Ozone treatment has a higher first cost, but it lowers lifecycle costs and water consumption. The labor costs for both chemical and ozone systems are about the same. Ozone may be the best option in municipalities with strict blow down water disposal regulations.

COOLING TOWER MAINTENANCE GUIDANCE

Maintenance	Description
	Daily
Overall visual inspection	Complete overall visual inspection to be sure all equipment is operating and that safety systems are in place.
	Weekly
Vibration	Check for excessive vibration in motors, fans, and pumps.
Fan motor condition	Check the condition of the fan motor through temperature or vibration analysis and compare to baseline values.
Check belts and pulleys	Adjust all belts and pulleys as needed.
Check tower structure	Check for loose fill, connections, leaks, etc.
Clean suction screen	Physically clean screen of all debris.
Test water samples	Test for proper concentrations of dissolved solids, and chemistry. Adjust blow down and chemicals as necessary.
Operate make-up water float switch	Operate switch manually to ensure proper operation.
	Monthly
Check lubrication	Ensure all bearings are lubricated per the manufacturer's recommendation.
Check motor supports and fan blades	Check for excessive wear and secure fastening.
Motor alignment	Align the motor coupling to allow for efficient torque transfer.
Check drift eliminators, louvers, and fill	Look for proper positioning and scale buildup.
	Annually
Clean tower	Remove all dust, scale, and algae from tower basin, fill, and spray nozzles.
Check bearings	Inspect bearings and drive belts for wear. Adjust, repair, or replace as necessary.
Motor condition	Check the condition of the motor through temperature or vibration analysis to ensure long life.

Refer to the *Operations and Maintenances Best Practices Release 3.0* guide, available through the DOE website, for more information on operating and maintaining efficient cooling plants.

Heating Systems

Heating systems that may be used in public housing in the Southwest include electric resistance heat; heat pumps; gas furnaces; and central steam, hot water, and radiator space heating systems. Each system is discussed with general guidance on operations followed by a maintenance guidance chart. Central steam and hot water have more components requiring specific maintenance, so some of these components have maintenance guidance charts of their own.

Electric Resistance Heat

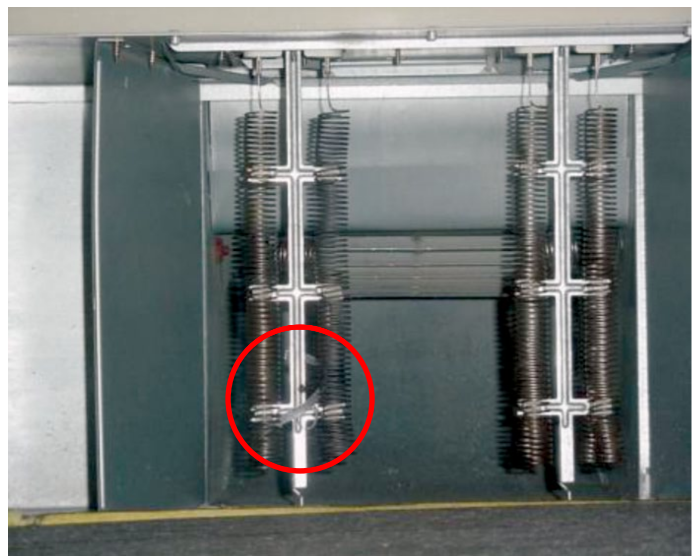
Electric resistance heat is the simplest but least efficient type of heating system, and may be found in the form of either baseboard or forced-air electric resistance heat.

Baseboard Heating Operation

Units located on exterior walls along the baseboards are known as "baseboard" heating units and rely on convection and radiation to transfer heat. They do not rely on air distribution fans and have little to maintain. Solid furniture should not be placed in front of baseboard heaters since doing so will limit both convective and radiative heat exchange to the room and create uneven space temperatures.

Forced Air Electric Resistance Heat Operation

Electric heating elements, or strip heat, are generally located inside an air handler unit, package terminal unit, or rooftop package unit. This form of heat can be designed to provide all of the heating. Alternatively, the strip heat may act as a supplement or back-up to a heat pump. Care should be taken to protect the heating elements from falling debris during service work. Airflow should be operated within the specific range designed for the heat strip. Cold supply air temperature complaints may be due to an airflow rate that is too high for the strip heater. When strip heat elements are first activated at the beginning of the heating season, a burning odor may be detected as dust and spider webs are burned off.



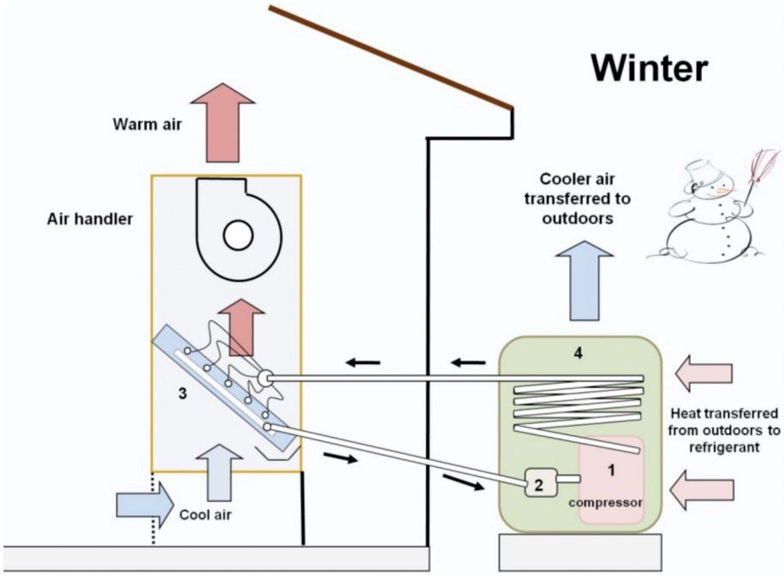
View of strip heat at top of an air handler. A metal shaving fell onto a strip during careless duct construction.

ELECTRIC RESISTANCE HEAT MAINTENANCE GUIDE

Maintenance	Description
	Annually
Heating elements	Inspect heat elements for corrosion or damage. Replace bad elements. Carefully vacuum dirty elements if needed and inspect duct system and filter assembly for entry points of dirt.
Heat stage	Test proper activation of various stages of heat in multi-stage heater.
Electric power	Inspect wiring and electric connections. Tighten loose wires and replace weathered or nicked wiring. Measure electric heat amperage under operation and verify it is within manufacturer's specifications. Repair or replace equipment operating outside specifications.

FIGURE 3. HEAT PUMP OPERATION IN WINTER

1) compressor 2) reversing valve 3) condenser 4) evaporator



Heat Pump Operation

A heat pump is an air conditioner that can also operate in a reverse cycle to provide space heat. To achieve this, a reversing valve allows the refrigerant to flow in the opposite direction. In heating mode, the outdoor coil becomes the evaporator, discharging cold air outdoors; the indoor coil becomes the condenser, discharging hot air indoors (see Figure 3).

Heating provided by heat pumps is about 2.5 to 3.5 times the efficiency of electric resistance strip heat, depending upon the outdoor temperature. The efficiency and capacity of a heat pump declines as outdoor temperature decreases. So, while a heat pump can still heat at 25°F, it does not deliver as much heat as when it is 40° outside. For this reason, heat pumps have strip heat available for especially cold periods. Note that adjusting the heating setpoint by 2 degrees or more will activate the strip heat, which can lead to considerable energy waste. This problem is avoided by programming the thermostat to disable the strip heat above a specific outdoor temperature. If the thermostat does not have that capability, an outdoor thermostat can be installed to serve the same purpose.

Heat Pump Maintenance Guidance

Maintenance of the heat pump air handler will be the same as that performed for maintenance of AHUs (see AHU section below). Maintenance of the heat pump outdoor unit is similar to condensing units.

HEAT PUMP MAINTENANCE GUIDANCE

Maintenance	Description
	Annually
Outdoor coil	Clean the outdoor coil and remove any debris such as leaves or dirt from around or near the outdoor unit. Repair damaged fins. Keep snow and ice cleared away and make sure defrost water melt can drain away from the unit without harming building. DO NOT attempt to forcefully remove ice build up from any part of the heat pump. Do use the cooling cycle or warm water to melt ice build-up.
Refrigerant leaks	Inspect tubes and coil for evidence of leaks. Have a leak test done and seal leak on system that requires refrigerant to be added.
Fan	Lubricate fan motor bearings according to manufacturer's recommendation. Inspect fan for damage or unusual vibration or noise. Tighten and adjust fan mounts as needed.
Electric power	Inspect wiring and electric connections. Tighten loose wires and replace weathered or nicked wiring. Measure heat pump amperage under operation and verify it is within manufacture specifications. Repair or replace equipment operating outside specifications.

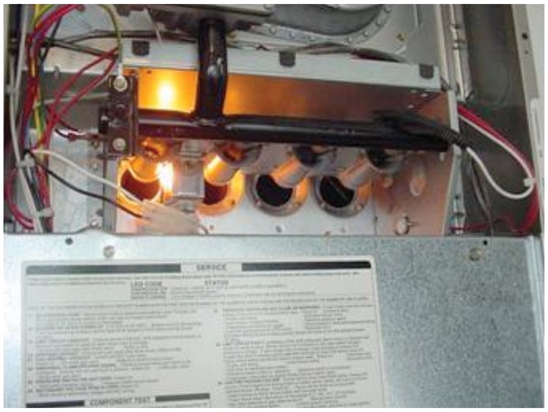
Gas Furnace Operation

Some PHA buildings use gas furnaces for space heating. Any space where gas combustion appliances such as a furnace or water heater are located is referred to as a combustion appliance zone (CAZ). A gas furnace consists of a metal cabinet, combustion components, and an internal fan to circulate heated air to the building. Furnace maintenance should focus on 1) fuel delivery, 2) fuel ignition and combustion, 3) heat transfer to air, and 4) combustion venting. When properly installed and maintained, these furnaces operate safely. However, problems related to any one of these four processes can result in unhealthy and sometimes lethal consequences.

Some considerations related to safe furnace operations include the following:

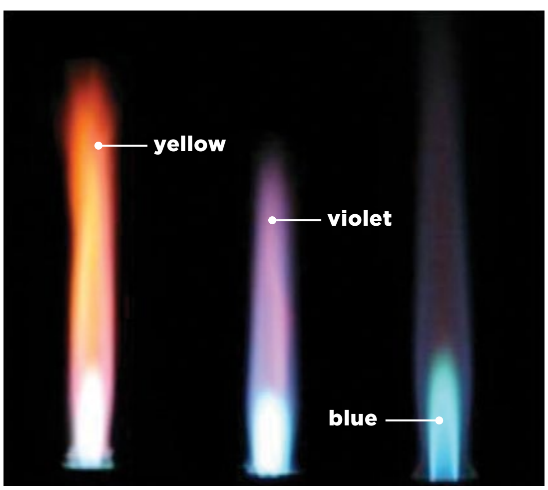
Gas furnace with panel removed. Cabinet and return duct leakage can interfere with natural draft appliances such as the gas water heater at left.

- **PILOT LIGHT:** Older furnaces have a pilot light that ignites gas once the gas valve opens. The pilot light should burn blue at the inner core of the flame and should also surround the thermocouple, causing it to glow red. A pilot light that has to be lit often may be a sign of building airflow imbalance. A building science expert familiar with unbalanced airflows and combustion systems should evaluate this circumstance.
- **ELECTRONIC IGNITION:** Newer furnaces have an electronic ignition that generates a spark to ignite fuel. The igniter should be aligned properly at the front of the burner. Furnaces with electronic ignition that fails to ignite after several attempts will go into a soft lock-out and will prevent further attempts to activate. Units that lock out often should be inspected by a qualified technician.



Furnace electronic igniter glowing brightly just before fuel is delivered.

Light blue flames indicate clean efficient combustion.



Three flames with varying fuel to oxygen ratio. The very yellow flame at far left needs more oxygen and will produce carbon monoxide and fine soot particles. The middle flame has improved oxygen supply, but still needs to produce complete combustion. The flame on the right produces clean and efficient combustion with no visible yellow and a clear blue tip.

- **COMBUSTION CHAMBER:** Once the gas ignites, it burns inside the combustion chamber. The flame should appear blue. Improper air-to-gas ratios produce yellow in the flame. Inspections should also look for sooty areas within the combustion chamber. A qualified service technician should service the unit if evidence of soot or yellow flame is observed. Complete combustion requires an adequate amount of air. In many cases, dilution air is also required. This dilution air enters the atmospheric vent and flows out of the building along with the combustion gases to dilute the combustion byproducts and reduce moisture condensation in the vent. Vent openings are provided into the combustion appliance zone in order to provide the required combustion air and dilution air. These combustion/dilution vent openings should comply with the National Fuel Gas Code, known as standard NFPA 54, and applicable codes, and should be inspected periodically to verify that no blockage has occurred.
- **STORAGE:** As a safety precaution, the building policy should prohibit storage in either mechanical rooms or mechanical closets that contain combustion appliances.
- **HEAT EXCHANGE:** Heat is transferred from the combusted gas through the heat exchanger located inside the furnace. Generally, the heat exchanger requires no maintenance. However, older systems should be inspected for cracks that could allow carbon monoxide (and other combustion gases) to enter into the building.
- **VENTS:** Combustion gas is vented to the outdoors through a vent. Older systems often use a natural draft (or atmospheric draft) vent to carry the combustion gases outdoors. The buoyancy force of natural draft can easily be overcome by space depressurization (caused by exhaust fans, return duct leakage, or AHU leakage), resulting in air quality problems such as spillage, backdrafting, or, in severe cases, flame rollout. Higher efficiency furnaces have fan-powered exhaust since the exhaust temperature is cooler and the draft strength is lower than natural draft. More details on combustion safety can be found in the Health and Safety section of this chapter.

GAS FURNACE MAINTENANCE GUIDANCE

Maintenance	Description
	Monthly or As Needed
Combustion/ dilution air	Verify proper clearance of objects from vents that admit combustion/dilution air into the space.
Air filters	Inspect and change as needed.
Motors and fans	Tighten belts and lubricate bearings.
Combustion	Inspect ignition, pilot light, and burner flame. Verify effective exhaust.
	Annually Prior to Heating Season
Ignition	Inspect pilot light for proper flame and that the thermocouple sensor is within the pilot light. Consider having a building science expert determine if frequently blown out pilot lights are caused by zone depressurization. Inspect electronic igniters to verify proper ignition. Have qualified service technician determine causes of ignition problems.
Combustion	Inspect flames in burners for clear blue flame absent of yellow. Service technician should be used to adjust and clean equipment if yellow flame, soot, or oversized or undersized flames are observed. Inspect combustion vents for damage or blockage. Repair as needed and in compliance with NFPA54. Using a gas leak detector, determine if fuel leakage is occurring at valves and fittings.
Natural draft exhaust	Inspect combustion exhaust vent for damage or blockage. A smoke puffer can be used to verify complete draft up natural draft exhaust vents with the unit operating. Smoke that wafts or "blows" back into space from the entry of the vent indicates incomplete draft, also known as spillage.
Powered draft exhaust	Ensure that the fan operates quietly. Combustion vent duct should be tightly connected to the fan. Perform inspection to verify that the combustion vent is not damaged, leaking, or blocked.
Heat exchanger	Inspect for a cracked heat exchanger by observing for flame modulation or yellow flame. Heat exchanger should be replaced if cracked. Carbon monoxide can be detected in the central air distribution system (after the heat exchanger) if there is a crack in the exchanger.
Lubrication	Ensure all bearings are lubricated per the manufacturer's recommendations.
Motor supports	Check for excessive wear, secure fasteners, and adjust alignment if needed.
Belts	Adjust belts and replace worn or damaged belts.

Central Steam, Hot Water, and Radiator Space Heating System Operations

Central steam and hot water systems are commonly used in large public housing buildings. In simple terms, these systems consist of a boiler that heats water and piping to distribute hot water or steam to radiators located in areas to be heated. The system also has piping that returns the cooler water or condensed steam back to the boiler. In most hot-water systems, pumps move the hot water from the boiler to individual radiators. Thermostats modulate the flow rate of hot water or steam to individual spaces. The boiler burner is activated as needed to maintain an internal boiler temperature, which may be reset based on outdoor temperature.

Distribution Piping Operation

Pipes circulate heated water or steam through the building. Insulate the distribution pipes (especially where the pipes run through unconditioned spaces), and inspect the insulation at least annually or after any service that disrupts insulation. Insulation should not be compressed or have gaps between sections. Replace missing or damaged sections. Address dripping from pipes immediately. Discard and replace wet insulation after pipe surfaces have been repaired and dried. Infrared cameras or spot thermometers can be useful in finding areas that need replacement.

Boiler Operation

Boilers come in different sizes and styles, but all are designed to provide hot water or steam. Boilers are typically either water-tube or fire-tube style. Relatively small boilers operate fairly simply and do not require as much maintenance as large boilers with more complicated systems and controls. In fact, some of the information covered here may not apply to small hot water (also known as hydronic) heating systems.

Keeping daily records of boiler operation is important to boiler maintenance. As a baseline, measure fuel consumption, flue gas temperatures, and water pressures and temperatures during periods when equipment is known to operate as expected. The baseline allows the operator to identify substandard performance and take corrective action before larger problems develop. For example, flue gas temperatures that gradually increase over a period of time could signal a build-up of scale, reduced capacity, and diminished efficiency. Keeping the system clean helps maintain efficiency, durability, and reliability.

Maintenance and operations can affect boiler efficiency, according to the EPA report *Wise Rules for Industrial Energy Efficiency:*

- Optimizing air-to-fuel ratio, burner maintenance, and tube cleaning can save about 2% of a facility's total energy use with an average simple payback of 5 months.
- Tune-ups using precision testing equipment to detect and correct excess air losses, smoking, unburned fuel losses, sooting, and high stack temperatures can result in boiler fuel savings of 2–20%.
- Boiler fuel use can be reduced 1–2% for each 40°F reduction in net stack temperature (outlet temperature minus inlet combustion air temperature).
- Removing just a 1/32-inch deposit on boiler heat transfer surfaces can decrease a boiler's fuel use by 2%.

- For every 11°F that the entering feedwater temperature is increased, the boiler's fuel use is reduced by 1%.

Water Quality in Boiler Maintenance

Municipal water has dissolved minerals, oxygen, and chemicals that can shorten the life of a boiler. Water chemical treatment and softeners are important elements of boiler maintenance to remove dissolved solids and hardness. Deaerators remove oxygen from feedwater to protect the boiler from pitting and corrosion. **In a boiler steam system operating below 300 psi, it is recommended that feedwater have less than 3500 PPM total dissolved solids, maximum alkalinity of 700 ppm, and hardness less than 20 ppm.**

The blowdown system is designed to remove larger pieces of sediment from the boiler. In steam systems, the condensate return unit captures condensed steam to be used again. This conserves water and treatment chemicals, and prevents chemical discharge to the city sewage system. Make-up water should be supplied by nonpotable sources when possible. This would require a catchment system to collect precipitation that can be delivered into the feedwater.

Combustion Equipment

Take care to maintain the combustion part of the boiler. The air and gas must not only be in correct proportion, but also properly mixed to ensure complete combustion. Gas pressure is controlled through a pressure regulator, and a fan controls the volume of combustion air. Combustion fan problems can seriously affect combustion efficiency. Excessive fan noise or vibration is an indication of worn or damaged parts.

Some possible causes for inadequate combustion air:

- Incoming air limited by poorly adjusted dampers or inlet vanes
- Fan inlet or outlet is obstructed
- Air leaks within the system
- Damaged blower wheel or bearings
- Worn or broken fan mount.

The table below provides general guidance for boiler maintenance. The DOE Federal Energy Management Program document *O&M Best Practices Guide, Release 3.0* is a good resource for details on boiler maintenance practices and inspection logs.

BOILER MAINTENANCE GUIDANCE

Maintenance	Description
	Daily
Water level	Inspect water level, test low water cut off. Consider metering feedstock water since this can help determine if system performance is dropping.
Blowdown	Perform blowdown to maintain clean boiler operations.
Visual inspection and record keeping	Make note of: Operating boiler pressure and temperature Feedwater pump operation Feedwater pressure and temperature Condensate temperature Flue gas temperature Gas pressure Oil pressure and temperature
Inspect combustion	Inspect the burner operation, look for signs of poor combustion such as soot, yellow flames, or over- or under-sized flames.
	Bi-Annually
Refractory	Clean and vacuum fireside surfaces as required. Inspect refractory for large cracks or missing pieces. Patch and wash coat as required. Inspect gasketing on doors and replace as needed.
Tubes	Inspect for soot deposits, pitting or deposits. Sooting can be an indication of a burner that needs adjustment. Pitting can be a sign of condensation of flue gas, which can occur due to short firing cycles. Increasing water temperature can produce longer cycles. White deposit on the ends of tube sheet can be a sign of leaks. A boiler service company may need to re-roll tubes.
Boiler / feedwater	Flush boiler with water to remove loose scale and sediment as needed. Check all hand hole plates and manhole plates for leaks at normal operating temperatures and pressures. Open feedwater tank manway, inspect and clean as required.
Combustion	Clean burner and burner pilot. Check pilot electrode and adjust or replace as needed. Clean air damper and blower assembly. Clean motor starter contacts and check operation. Make necessary adjustments to burner for proper combustion and record all results in service report. Perform all flame safeguard and safety checks and record results in service report.
Controls	Clean and inspect low water cut off controls. Remove plugs in control piping; inspect, clean and re-install.
Water treatment	Inspect chemical treatment tanks and pipes for leakage. Check water for proper quality per manufacturer recommendations.
Condensate return	Inspect condensate return pumps for leakage; inspect motor and measure motor amps.
	Annually
Blowdown piping	Inspect piping for obstructions.
Boiler tubes	Clean at least once a year or more often if needed.

Radiator Operation

The radiator transfers heat from the hot water or steam to the conditioned space. Some important things to address for good radiator operations include:

- **TRAPPED AIR IN A HOT WATER SYSTEM:** Over time, air can enter a hot water system, decreasing system efficiency, and should be removed.
- **TRAPPED WATER IN A STEAM SYSTEM:** A banging sound as the radiator begins to heat is a sign of trapped water in a steam system. Steam radiators should have appropriate tilt to allow all condensed water to drain. Tilt should be toward the drain in a one-pipe system and toward the steam trap in a two-pipe system.
- **STEAM TRAP:** A steam trap that needs to be replaced may cause poor temperature control.
- **INSULATION:** Placing insulation or reflective surface behind the radiator will minimize the heat loss to outside. The reflective surface should be durable and cleanable.
- **VENTS:** Steam radiator vents should also be maintained. Vents allow air in the radiator to exit as steam comes into the radiator. They should close once steam reaches the vent. Failure to close properly results in a loss of steam into the space, which can result in overheating of space and wasted energy. Prolonged whistling or air noise indicates that a vent should be cleaned or replaced.

RADIATOR MAINTENANCE GUIDANCE

Maintenance	Description
	Annually or As Needed
Hot water system water level	Bleed air from radiators in hot water systems before the heating season begins.
Zone control	Verify that zone controls work by manipulating thermostats and observing appropriate valve control response.
Steam radiator mounting	Verify proper tilt for draining condensate back to boiler.
Steam system air vents	Inspect vents during operation to verify the close properly and do not allow steam to escape. Clean or replace as needed.
Heat reflector surface	Clean reflective surfaces located behind radiators and secure loose mounts as needed.

Steam Trap and Valve Operation

As steam enters the radiators and releases heat into space, some water vapor condenses into water that must be removed from the steam system. Steam traps are devices that allow condensed steam (condensate) to be released without releasing steam. Some systems release the hot water to a drain, which wastes water and energy resources. In contrast, better designed systems pipe the condensate back to a collection point to use as feedwater as needed.

Control valves are used to limit water or steam flow, and pressure relief valves maintain safe operating pressures. Various types of valves used in the water or steam distribution system rely on seals that can become worn over time and develop leaks.

The DOE reports that facilities lacking advanced steam plant maintenance programs can lose 20% of the steam generated through leaking steam traps (typically located in unconditioned space so that lost energy escapes to outdoors). Even small losses of steam should be taken seriously because so much energy is required to change water to steam. Programs that use the best equipment and programs can reduce steam leak losses to less than 1%.

STEAM TRAP AND VALVE MAINTENANCE GUIDANCE

Maintenance	Description
	Daily
High pressure steam traps (>250 psig)	Inspect for steam leakage. Short inspection interval is recommended since large quantities of steam can be lost at high pressure traps. Clean or repair as needed, replace when cleaning is no longer effective or about every 3-4 years. Verify that replacement traps are proper trap size.
Pressure relief valves	Inspect for chattering or water leaking. Repair seals or replace valves as needed. Valves rarely utilized in well-maintained systems may last several years before requiring replacement.
	Weekly
Pressure traps operating between 30-250 psig	Inspect for steam leakage. Clean as needed, replace when cleaning is no longer effective.
	Monthly
Pressure traps operating below 30 psig	Inspect for steam leakage. Clean as needed, replace when cleaning is no longer effective.

Air Distribution Systems

In most buildings, HVAC is distributed by means of an air distribution system (ADS). The *intended* goal of the ADS is to deliver air to various spaces in order to maintain desired temperature, RH, and air freshness. The ADS includes fans to move air, heating and cooling systems to condition the air, outdoor air and exhaust systems to control air exchanges with outdoors, and filters to control particulate levels in the air. This section first discusses background and issues, then covers operations and maintenance priorities.

Background and Issues

Poorly designed or maintained air distribution systems also produce *unintended* effects. For example, air distribution leakage can diminish the heating and cooling capacity of the system, increase energy use, and cause poor indoor air quality.

Duct Leakage

Duct leakage is a large problem in commercial buildings. One study found air leakage from commercial building ducts to be 70 times greater than the Sheet Metal and Air Conditioning Contractors National Association (SMACNA) standard for duct air-tightness. If the ducts are located outside the air and thermal boundary of the building, then these leaks create large energy losses. They also create unbalanced airflows, which produce positive or negative building pressure, which in turn moves air across the building envelope air boundary. If the duct leakage occurs inside the building air and thermal boundaries, then the effects of energy, airflow balance, and space pressure are greatly muted. Even relatively small portions of the air distribution system, such as the AHU, can have significant impacts on duct leakage. This can happen even if the rest of the duct system is very tight. One study of 69 AHUs in Florida found that more than 4% of the total system airflow was leaking into the cabinet of the typical AHU. Leaks in the AHU cabinet may be relatively small in terms of surface area, but because the operating pressures in the AHU are large, the resulting air leakage into the unit may be quite large.

Leakage in the ventilation ductwork can also occur. The air that leaks into outdoor air ducts from *within* the building air boundary diminishes the amount of “fresh” ventilation air, and may also draw contaminated air from attics, crawl spaces, and basements into the building. In the case of exhaust duct leakage, keep in mind that poorly conducted Test and Balance may add to the problem:

- The air drawn from the building through leaks will add to total building ventilation, but will not show up in measurements of exhaust at the grills.
- Test and Balance will typically measure exhaust only at the exhaust grills; therefore, part of their HVAC adjustments may increase total exhaust fan flow rates to achieve the target airflows at the grills.
- As a result, the building may become more depressurized as a result of Test and Balance work.

Unexpected Interactions

There can sometimes be other unexpected interactions between features of the ADS. For example:

- **LOCATION AND TYPE OF AIR FILTERS:** The location and type of filters can affect both the quantity and consequences of duct leakage. Air filters, which are typically intended to keep ducts, coils, and fans clean, are typically located at either the AHU or at grills. If filters are located at return grills, the return ductwork will operate under greater levels of negative pressure. Greater negative pressure, in turn, causes greater airflow through the return leak openings. Additionally, the air leaking into the return ductwork can carry dust into the system, which will not be filtered because the filter is upstream of the leak sites. By contrast, if the filter is located at the AHU, then the return ducts will be less depressurized, less return leakage will occur, and the dust entering those leaks will be filtered as it enters the AHU. Overall it is best to have a tight duct system with filtration at grills to keep the return duct cleaner.
- **RETURN AIR IMBALANCE:** Some buildings experience return air imbalance, which occurs when the amount of return drawn from a zone is greater or less than the amount of supply air delivered to that zone. This is especially common in buildings where the return(s) are located in the central space while supply air is delivered to rooms that can be closed. When doorways between the interior spaces are closed, the return versus supply imbalance can create either negative or positive pressure in that space, and this pressure can in turn move air across the building envelope. Unbalanced return air can increase the building infiltration rate and, during cold and dry weather, can decrease indoor RH below comfortable levels. In some cases, space depressurization can increase the rate of radon or other soil gas into the building. In other cases, this depressurization can cause combustion safety problems (see the Health and Safety section below).

  Improve unbalanced return air by either adding ducted return air to each space that has a door and supply air, or by installing air transfer pathways from the closable room to the central space where return air is located. Transfers may be simple grills through a wall or door. Another method of transfer is to install a short section of duct in attic or ceiling space. The transfer duct is connected to a grill in the room ceiling with the other end connected to a grill in the central space ceiling.

In some cases, the amount of supply air delivered to a space is not proportional to the heating or cooling loads. This can lead to temperature variations and comfort complaints.

Air Distribution System Operations

Pressure Mapping

Pressure mapping can identify when the building or zones within it are operating at positive or negative pressure. This data can provide clues to duct leakage or unbalanced return air. Pressure mapping involves measuring pressures from one room compared to another. These measurements are made quickly using a micromanometer with the AHU operating. Pressures across closed doors should be less than 2.5 pascals (0.010 in WC).

Duct Air-tightness

Duct leakage is very common in light commercial buildings, such as PHA office and common spaces, where it has been found to be about three times greater than in residences. Testing for duct system air-tightness can be useful to understand the performance of HVAC systems and to correct energy waste. It can also help to understand high building infiltration rates or large building pressure differentials. A thorough duct tightness evaluation will involve a tightness test as well as visual inspection. The tightness test uses a special fan to depressurize the duct system to 25 pascals of pressure. The leakage airflow is measured as cubic feet per minute (CFM) at 25 pascals, so the test result is often noted as CFM25. Most ductwork in public housing would fall under the lower pressure classifications typically used in small commercial and residential construction.

A good duct tightness goal for existing ducts in public housing common spaces should be about 0.05 CFM25 / cfm of rated airflow. This would be total leakage of the system divided by the maximum rated airflow of the air handler unit on the duct system being tested. This goal can also be stated as follows: **The total duct leakage, CFM25, should not exceed 5% of the maximum rated airflow (cfm) of the heating/cooling system being tested.** It may be difficult for some systems to reach this goal if the duct system has limited access that prohibits sealing portions of the ducts. Visually small seams and cracks do not appear as significant leaks, and it can even be hard to feel leakage, but they may also have to be sealed to meet a 5% leakage goal.

To improve duct air-tightness:

- Start a visual inspection at the AHU.
- Inspect and seal seams, holes, and penetrations in the AHU cabinet.
- Pay special attention in reinstalling filter access panels after changing filters because such an opening can easily lead to serious depressurization of the mechanical room and perhaps cause backdrafting of combustion appliances.
- Inspect every connection and seam at least once, or after any duct alteration.

- Seal connections with duct mastic according to SMACNA and North American Insulation Manufactures Association (NAIMA) standards.

Cooling and heating energy savings can vary depending on how much of the duct system is within the air and thermal boundaries of the building. Even duct systems within conditioned space should be reasonably tight to ensure better air quality control. Tighter ducts can result in energy savings from reduced fan power in variable air volume systems.

Filtration

Inspect filters regularly. Replace or clean filters when visual inspection indicates dirt build-up, or based on pressure drop across the filters, or on a pre-arranged schedule. In general, avoid replacing filters before they become dirty because this unnecessarily adds to maintenance costs and puts additional load on landfill. Filtration efficiency is classified by Minimum Efficiency Report Value or MERV. Generally, use filters with MERV ratings in the range of 5 to 8.

Filters located at the return grills will cause the ductwork to operate under a higher level of depressurization. Leaky return ductwork will not only lead to increased levels of air leaking into the ADS, but also the unintended airflow will be unfiltered. This entry of dust and particulates can lead to fouling of the heating or cooling coils, and of the ADS interior surfaces. This can foster the growth of mold within the ADS.

Temperature and RH Logging

Indoor temperature and RH can be tracked with logging devices. These logging devices are relatively inexpensive and yet provide powerful diagnostic assessment. The collected data identifies patterns of temperature or RH that can identify system performance problems.

Temperature and RH can be logged at returns and at supplies to identify whether the heating or cooling system is providing conditioned air within performance expectations. For example, the difference in temperature between the supply air and return air should be approximately 18–20oF for an air conditioner using direct expansion equipment. The temperature difference between supply and return is much higher for gas furnaces. Supply air temperatures for most furnaces are designed to be around 40–60oF higher than the return air. Measurements outside manufacturer specifications should prompt further investigation of the system. Causes of low temperature differences can be related to improper refrigerant charge or return duct leakage.

Occasionally, improper thermostat connections made during service allow cooling equipment and strip heat to come on at the same time, resulting in a difference of just a couple degrees between return and supply. Measuring amperage of AHU would determine if the strip heat is activated.

Other aspects to measure for potential improvements:

- **TEST AND BALANCE THE HEATING AND COOLING SYSTEMS:** Test and Balance can be performed to characterize and make adjustments of airflow rates to spaces and should be completed if no record exists or changes have been made to the building or to its HVAC systems. System performance testing can be a useful tool, especially for DX air conditioning and heat pump systems. Perform engineering calculations to convert the measured airflow rates, return and supply temperatures, and supply and return RH into cooling or heating capacity. Compare these calculated values to rated capacity (taking outdoor temperatures into account) to help determine if servicing of the units is warranted.
- **TEST AND BALANCE THE VENTILATION:** Test and Balance firms can also measure the airflow rate of outdoor air and exhaust systems, to confirm whether the required ventilation rates are being achieved. This should also be done if there are no records of previous work or changes have been made to the building or air distribution system. The best location to measure exhaust flows is where the airflow crosses the building envelope (e.g., at the roof). While this will not, in itself, verify that air is taken from each space as designed, it will provide the total airflow from the building. Testing of the exhaust ductwork can determine if significant leakage exists.
- **VARIABLE AIR VOLUME (VAV) SYSTEMS:** With chilled water systems (and some DX systems), the AHUs are often VAV with duct static pressure control. Individual VAV boxes adjust supply airflows to the spaces they serve to maintain the desired space temperature. The speed of the AHU fan is adjusted based on measurement of static pressure in the main duct. When VAV box dampers open to provide more heating or cooling, the AHU fan speed is increased to maintain this static pressure. Achieve energy savings by tuning the operation of the VAV boxes and implementing static pressure reset (e.g., lowering the duct pressure setpoint when airflow needs are reduced). Calibrate the static pressure control and inspect the VAV box damper control annually. Maintenance should include inspection for poor connections or cracked tubes of tubing connected to pressure sensors.

AIR DISTRIBUTION SYSTEM CHECKLIST

1. **PERFORM PRESSURE MAPPING** when any modifications affecting system airflow or distribution are made to the HVAC system, to the building envelope, or to interior partitions. Measure building pressure with the outdoor air (OA) normally open and with it sealed off, and with the AHUs on and off.
   - If the building or spaces within the building are found to be operating at negative pressure, look into the causes of these pressure differentials, including duct leakage, unbalanced return air, and exhaust fan operation.

2. **PERFORM DUCT LEAKAGE TESTING,** if it has never been done or after any HVAC duct modifications, especially:
   - if the ductwork is located outside the building air and thermal barrier,
   - if visual inspection yields suspicion of duct air leakage,
   - if pressure mapping finds the building pressure changing when the AHUs are turned on and the OA is sealed, or
   - if utility bills are larger than expected.

3. **ARRANGE FOR LEAKY DUCTS TO BE SEALED,** using mastic and embedded fabric. Seal cracks, openings, and penetrations in AHU cabinets.

4. **INSPECT FILTERS ON A REGULAR BASIS** (e.g., monthly). Replace or clean filters when visual inspection indicates dirt build-up or based on pressure drop across the filters. Filters with MERV ratings in the range of 5 to 8 will filter well and limit static pressure increase. While filters can be replaced on a pre-arranged schedule, avoid replacing filters before they become dirty because this wastes resources and puts additional load on land fill. If filters are located at return grills, take steps to ensure that the return ductwork does not have significant air leakage, since this can cause contamination of the ADS.

5. **IF HIGHER MERV FILTRATION IS CONSIDERED, CHECK DUCT STATIC PRESSURE** to verify system operation is within the air handler manufacturer's recommended values. If static pressure is too high, the filter surface area may need to be increased. Filter surface area can be increased by going to a deep-pleated filter or fabricating a larger filter rack. Deep pleated filters have a higher first cost, but last longer and may have a lower lifecycle cost.

6. **CONSIDER MEASURING SYSTEM AIRFLOW,** as well as temperature and RH, at returns and supplies as needed in zones with comfort complaints. This information can be used to characterize the performance of AC or heat pump systems and indicate whether servicing of these systems is required.

7. **CONSIDER PERFORMING TEST AND BALANCE ON THE HVAC SYSTEMS:**
   - If significant changes are made to the HVAC systems (e.g., AHU replaced, ducts added, or new building addition),
   - if pressure mapping finds significant pressure imbalances, or
   - if comfort problems are reported and not easily remedied.

   If airflows are found to be out of compliance with the design documents, make sure that these airflows are properly adjusted.

8. **WITH VAV SYSTEMS, PERIODIC COMMISSIONING OF THE AHU AND VAV BOX CONTROLS IS RECOMMENDED** (e.g., every 5 to 10 years). Consider implementation of static pressure reset (which would be implemented automatically through the building automation system when total heating or cooling load is reduced) to achieve energy savings. Check dampers and linkages to ensure that intended airflows are achieved in response to the automation system controls.

9. **INSPECT ALL REGISTERS FOR RESTRICTIONS TO AIRFLOW** such as covers over supply vents or furnishings placed in front of return or transfer grills.

Air Handler Units

Inside view of AHU with blower above evaporator coil. Electric heat element is located above the blower.

Air handler units (AHUs) distribute conditioned air and are available in a wide range of sizes, depending upon the amount of air to be distributed throughout a zone. An AHU consists of a metal cabinet and an electric powered fan. The AHU may also contain cooling coils, heating coils, and electric resistance heating elements. Classifications of air handling units depend on where and how they are used. Three types are commonly used in PHAs:

- **FAN COIL UNIT:** This unit is simply a cabinet with a fan and a heat exchange coil inside. Fan coil units are typically associated with chilled water systems.
- **ROOF TOP PACKAGE UNIT (RTU):** An RTU consists of a metal cabinet that contains not only the air distribution blower, cooling and heating exchangers, but also all of the components that would normally be in the outdoor unit of a split DX air conditioner (the compressor, the condenser, and the condenser fan). As the name implies, RTUs are designed to be located on rooftops requiring only a return and supply duct connection to be made to them. They vary significantly in size from 3 to well over 100 tons, serving areas of perhaps 1,000 to 50,000 square feet and more. Outdoor ventilation air is drawn into an opening in the side of the cabinet. Some RTUs are specially designed to condition 100% outside air.
- **PACKAGE TERMINAL AIR CONDITIONER (PTAC):** A PTAC is a self-contained unit like an RTU except it is generally much smaller and is designed to be installed through an exterior wall. PTACs may provide heating by means of electric resistance elements or heat pump. They are designed to distribute conditioned air into a small open area without a duct system.

PTAC unit was not tilted toward the drain correctly and water spilled from condensate pan onto carpet below.

Sealing AHU Panel Leakage and Penetrations

Air handler units (AHUs) are not, by design, airtight. In most cases, they come from the factory with leaks at a variety of seams and penetrations. After an AHU has been installed, additional leakage may exist. Many AHUs used in common areas of PHA property are residential class units. Manufacturers rely on technicians to properly seal penetrations where wiring and refrigerant lines penetrate the cabinet. Relatively small holes or cracks may seem too small to have much

Roof top package unit leakage through loose panels.

impact. However, since the fan is located in the AHU, air pressure inside the AHU cabinet is higher than at any other location in the air distribution system. This powerful pressure differential can produce substantial air leakage through even very small holes. Many AHUs have a draw-through design, resulting in most of the cabinet under negative pressure, which means air leakage gets sucked into the cabinet instead of blown out. Even new AHU cabinets can leak about 4% of the total system airflow.

The energy penalty of this leakage varies considerably depending upon the AHU location. If located inside the building, these leaks may cause little or no energy use increase. However, if located in an attic, system efficiency from AHU cabinet leakage alone during the hot hours of the day can decrease system capacity and efficiency by more than 10%. This type of leakage can have two types of significant impacts:

- **INCREASED ENERGY WASTE:** Depending upon unit location, AHU cabinet leakage can increase cooling energy costs by 10% or more during cold weather.

- **POOR AIR QUALITY:** Air leaking into the AHU cabinet carries unfiltered particles such as allergens, mold spores, and dust. These materials can build up on surfaces inside the AHU, including the cooling coil, insulation materials, fan motor and blades, and condensate drain pan. This build-up of dust and dirt can become the nutrient for mold growth, which can become widespread inside of AHU cabinets. Air handling equipment in locations such as garages, crawl spaces, attics, mechanical rooms, or shops will draw any pollutant present in those spaces, including carbon monoxide, into the conditioned space.

AHU cabinet leaks are generally easy and inexpensive to repair. Gasket material is best to seal panel seams, since it should not have to be replaced every time the access panels are opened. Tape is a temporary alternative, as it will not hold well when exposed to rain or extreme temperatures. Tape adhesive also leaves a grimy residue on panels and has to be replaced every time service panels are opened. Penetrations should be sealed carefully using HVAC putty. While foil tape can be used to seal panel seams, it does not effectively seal around wire and pipe penetrations.

Evaluating Moisture Problems Inside the AHU

Even though the southwestern region is much drier than other parts of the country, there are some circumstances that can result in moisture problems at the air handler. Condensation on lower portions of the AHU exterior or water dripping from the AHU can indicate internal moisture problems.

As initial steps:

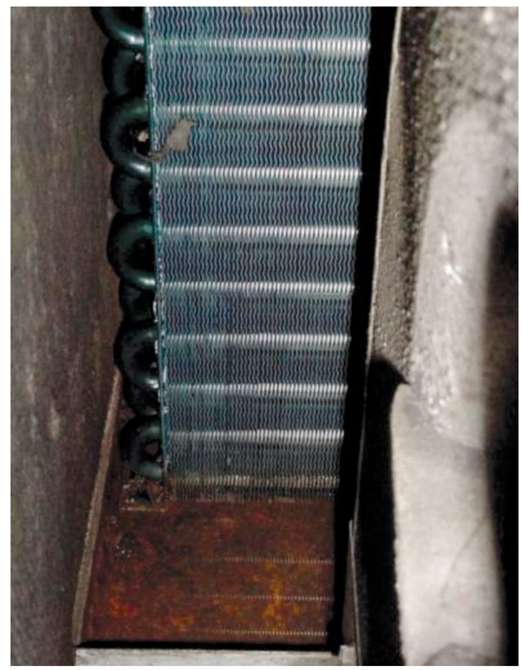
- **INSPECT THE INSIDE SURFACES OF THE BOTTOM PANEL** of the AHU for water or wet insulation. A section of panel insulation will likely have to be pulled back for this inspection. The panel surface and insulation should be dry. If wet, look first at the drain pan to ensure it is not full or spilling over.
- **INSPECT THE DRAIN PAN** to verify there are no leaks. The exterior sides of the drain pan should be dry with no evidence of watermarks.
- **LOOK FOR EVIDENCE OF MOISTURE BLOWN FROM THE COIL** onto surfaces downstream. This can occur when air velocity is too high for a particular coil, which might require duct or airflow modifications.

Wet building materials that cannot dry out also provide an excellent environment for mold growth. Proper condensate trap design is often overlooked. Traps should be deep enough to ensure that they do not dry out easily, that the traps do not leak water, and that air handler pressure cannot suck water back into the system.

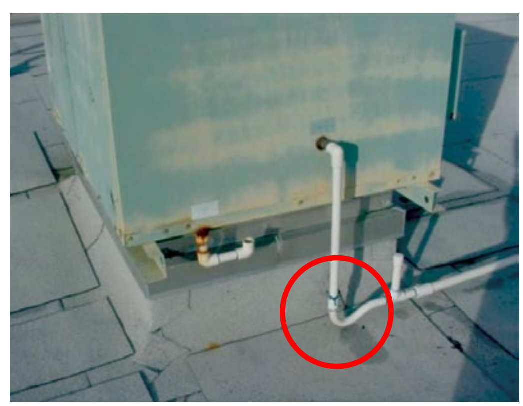
Cleanout caps should remain closed to avoid air rushing into the drain line and restricting drain pan drainage. Open condensate lines act as a duct leak. In some draw-through type air handlers, this air has high enough velocity to splatter water collected in the drain pan onto interior surfaces. Maintenance programs should evaluate the traps to determine if modification is needed. (For more information on air conditioning condensate trap design, refer to an article in *Heating/Piping/Air Conditioning Engineering Magazine* at http://hpac.com/air-conditioning/condensate_traps_brusha/)

One last thing to consider is where the air conditioning condensation line ends. Termination points should be located in places that will not be exposed to toxic substances that could adversely impact air quality in the event the trap becomes empty.

Condensation at bottom of air handler caused by wet interior insulation, rendering the insulation useless.



Standing water in pan below a clean cooling coil. Corrosion or sludge can result in water spilling over pan.



A primary condensate trap (right) and secondary trap on a rooftop package unit.

Condensate lines should never be terminated inside sewer lines, near combustion vents, or near the ground where pesticides may be applied.

AIR HANDLER MAINTENANCE GUIDANCE

Maintenance	Description
	Weekly
Unit inspection	Observe each unit to verify that it is operating as expected. Indications of problems should be recorded such as: • excessive vibration and uncharacteristic noise (squeak, rattle, hum), • loose access panels and unsealed cabinet penetrations, • surface condensation or dripping off of cabinet, and water leakage from the drain pan.
	Bi-Annually or As Needed
Vibration	Immediately inspect systems with excessive vibration in motors and fans.
Fan motor condition	If a problem with the fan motor performance is suspected, evaluate through temperature or vibration analysis compared to baseline values. Electric performance can also be measured using a power analyzer and compared to manufacturer specifications.
Check belts and pulleys	Adjust all belts and pulleys.
Bearing lubrication	Ensure all bearings are lubricated per the manufacturer's recommendation. Sealed bearings may not need maintenance. Elevated temperature at bearings is an indication of advanced wear.
Motor supports and alignment	Check for excessive wear, adjust and secure fastening as needed. Align the motor coupling to allow for efficient torque transfer.
Cabinet insulation	Inspect the condition of insulation inside the air handler to look for damaged or missing sections. Check to see if insulation is wet and determine cause. Repair or replace insulation as needed.
Clean interior air handler, coil and fan blades	Inspect the interior of the AHU. Clean as needed. A good filtration program will keep equipment clean and minimize the need for time-consuming cleaning. If filters are located at the return grill, then dust entry may be occurring through return duct leaks. Consider repairing the return leaks or locating an additional filter in the AHU. Also make sure that outdoor ventilation air is filtered prior to entering the AHU.
Inspect blower drive	Inspect drive belts, pulleys, and bearings for wear. Adjust, repair, or replace as necessary. Some blowers are connected to a motor indirectly through a belt drive. Lubricate unsealed bearings.
Cabinet leakage	Check that panels fit tight with gaskets providing complete seal. Repair bent panels and replace damaged gaskets and missing screws. Make sure that filter access panels are put back into place and sealed tightly. All penetrations should be sealed.
Filter rack	Carefully inspect filter rack to see that it holds all filters tightly in place with no gaps either between filter sections or around the filter rack assembly. Repair deficiencies that permit air to bypass filters. Replace filters according to schedule or alternatively based on static pressure across the filters. Replace when pressure target is reached.

Maintenance	Description
Condensate	Inspect drain pan for cracks or leaks. A system that properly drains condensate and is operated cleanly should not have the presence of sludge in the pan. Drain pan should slope towards drain and be free of any sludge. Clean and disinfect drain pan if there is evidence of microbial sludge. Flush out condensate drain traps and lines. Make sure the condensate drain line has a trap. Make sure traps are full of water and functioning properly.
Moisture inspection	Inspect during hot and humid weather. The interior of the air handler should be dry, with the exception of the cooling coil and the drain pan.
Electric	Verify that service power and control wire connections are tight. Replace wires that have damaged insulation jacket. Replace missing or damaged electric service cover plates.

Ventilation

Ventilation is the process of intentionally moving air between the indoors and outdoors to maintain acceptable indoor air quality. This section provides a fuller understanding of the issues related to ventilating PHA common spaces.

Background and Issues

Outdoor air (OA) introduced through the central heating and cooling system dilutes indoor contaminants and produces pressurization of the space. Exhaust fans can capture air contaminants that are contained within a specific zone and also dilute contaminants. They produce space depressurization. The requirements for ventilation for specific types of buildings are listed in building codes and in applicable standards, such as ASHRAE Standard 62.1. Many jurisdictions have adopted the requirements of the ASHRAE standard.

Air Infiltration

Infiltration, which can be understood as the unintended introduction of outdoor air into a building, can contribute to space ventilation. Infiltration can occur either by means of natural infiltration (driven by the forces of wind or temperature differential) or by mechanically driven forces (driven by duct leaks, unbalanced return air, etc.). In most cases, infiltration cannot be counted on to provide reliable and predictable ventilation. Several types of tests, performed by trained and qualified contractors, help the facility manager understand the amount of air exchange that is occurring because of infiltration or from operation of the ventilation systems:

- Blower door testing can measure the envelope air-tightness, which can predict "ballpark" natural infiltration.

- Duct air-tightness testing can help determine the levels of mechanically induced infiltration (especially if the ducts are located outside the envelope air boundary) that occur when the AHU fan is operating.
- Tracer gas decay testing can characterize the actual air exchange rate under specific operating conditions.

Ventilation from Outdoor Air

Unlike infiltration, ventilation is the *intended* introduction of outdoor air into a building. Ventilation can be implemented by introducing OA into the heating or cooling system, where it can be conditioned and distributed to the occupied space.

Scheduling of OA ventilation can create problems. In many systems, the AHU fan cycles on and off (fan AUTO) in response to the call for heating or cooling. When OA is introduced through the system and the AHU cycles, the amount of ventilation air delivered to the space is a function of the heating or cooling load. Periods of high load produce greater ventilation, while periods of little or no load lead to little or no OA introduced into the space. Alternatively, the AHU fan can be set to operate continuously (fan ON), thereby providing ventilation air continuously.

Drawbacks to continuous AHU fan operation include:

- Air leakage in the ductwork or AHU cabinet can create energy losses and lower indoor RH levels when outdoor dew point temperatures are low.
- Conductive losses and air leakage losses from ductwork can increase heating loads, increase fan energy consumption, increase utility costs, and waste energy.
- During the cooling season, moisture remaining on the cooling coil can be evaporated back to the space when the compressor cycles off, raising indoor RH by as much as 20%.

FIGURE 4. NEGATIVE PRESSURE CREATED BY OUTSIDE AIR
When exhaust air exceeds the air flow that is pumped into a building, the space can go to negative pressure. This can result in excessive infiltration rates and combustion safety problems.

Ventilation from Exhaust Systems

Exhaust systems can also create ventilation. While OA is introduced through the central space conditioning system and produces positive pressure in the building, exhaust fans draw air from the building and may create negative pressure (Figure 4). Negative pressure, or depressurization can create combustion safety problems discussed in the Health and Safety section below.

Ventilation Operation

Filtration

The OA introduced into the central system should be filtered in order to avoid dust and particulate build-up on the heat exchange surfaces of the system (coils and heat exchangers) and internal surfaces of the distribution system. OA filters may need to be replaced or cleaned more frequently than circulation air filters.

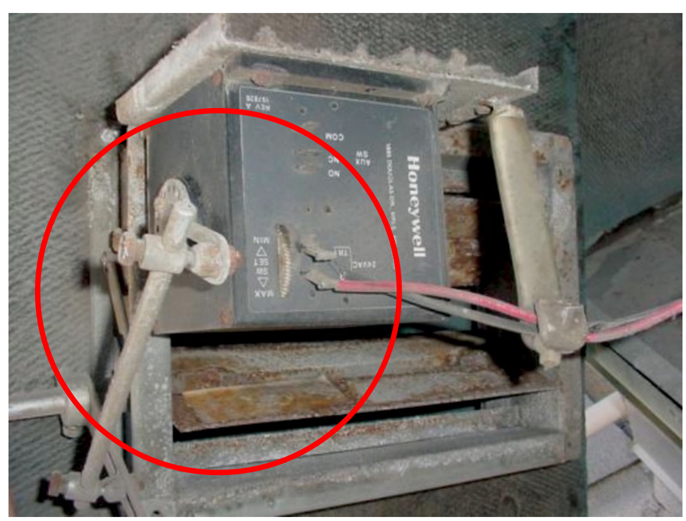
Outdoor Air Intake

Where to locate the OA intake is as much a matter of where not to locate it:

- The OA intake should not be located within 25 feet of contaminated sources such as the discharge of exhaust fans or plumbing stacks.
- OA should not be drawn from locations near garbage dumpsters or loading docks.
- Designated outdoor smoking areas should also not be located within 25 feet of air intake.
- Introduction of contaminated air during special events should be avoided. If a new roof (such as hot-mop asphalt roofing) is being installed, for example, seal off the OA during the period while chemical vapors are being emitted. Likewise, if outdoor smoke (such as from nearby forest fires) or smog exists, shut down the OA intake. It will be important to re-open the OA vents when the temporary air contamination event has passed.

Ventilation Requirements

Commissioning or retro-commissioning should be implemented for the HVAC systems to make sure that sufficient ventilation air is provided to the space. Damper settings, linkages, and control sequences should be checked and adjusted. It is common for OA dampers/linkages to lose functionality because of corrosion, especially in coastal areas because of air-borne salt. Once Test and Balance has been implemented, mark damper settings so that staff can verify proper damper position. Ventilation can be spot-checked by means of a portable carbon dioxide (CO_2) measurement device. People breathe out CO_2 as a byproduct of respiration. Thus, while CO_2 is not a pollutant at normal levels, it can be a flag to indicate if ventilation rates are sufficient. Indoor CO_2 levels significantly above



Small ventilation damper showing signs of damper and linkage corrosion.

about 1000 parts per million (ppm) after 3–4 hours into the work day indicate insufficient ventilation for an office space.

Table 1 shows the indicated ventilation rate per person for different measured indoor carbon dioxide concentrations after 3–4 hours into the work day (assuming an outdoor concentration of 400 parts per million).

TABLE 1. CO_2 THAT RESULTS FROM VARIOUS VENTILATION RATES AFTER A SEVERAL HOUR EQUILIBRIUM PERIOD

Carbon Dioxide Concentration (ppm)	cfm per person
2520 ppm	5
1460 ppm	10
1100 ppm	15
930 ppm	20
824 ppm	25

ASHRAE Ventilation Standard 62 recommends different ventilation rates for commercial property based on type of use and area of the space, as well as the design occupancy. Most PHA common areas can be ventilated effectively at about 15 cfm/person while occupied. While under-ventilation is a problem to avoid, excessive ventilation can create substantial problems as well, including the potential of not meeting space conditioning loads (comfort problems), energy waste, or low indoor RH during periods with dew point temperatures below 40° F. Older buildings may have been built when recommended ventilation standards were much lower. This means that the air conditioning equipment may be sized for only 5 cfm/person. Bringing more OA into such systems can challenge the capacity of the space conditioning systems.

Scheduling Ventilation

Since ventilation adds to heating and cooling loads, it should be turned off or modulated during periods when the building has no or reduced occupancy. Exhaust fans can be programmed to turn off during “after hours” periods, and OA dampers can be automatically closed. Operating this way avoids energy waste and low indoor humidity. Even when the building is occupied, occupancy may not be constant. More advanced ventilation control can “sense” the number of people in the space through measurement of CO_2 in the indoor air and adjust the position of the OA damper. Keep in mind that if OA is reduced but the exhausts continue to run, then the space may go to negative pressure which could create combustion safety problems. If the HVAC system uses CO_2 sensors to control ventilation, it will be important to check the calibration of these sensors on a yearly basis. New CO_2 sensors can be added to existing systems for about $1,100 each ($250 for the sensor and $800–$900 for installation). This can be cost-effective for zones with highly variable occupancy that are difficult to predict by schedule. If occupancy is reasonably predictable, then control of ventilation by a clock schedule is more cost-effective.

Avoiding Health and Safety Problems

Hot and dry climates are, in many cases, dusty. It is important in these cases to filter the OA to keep dust from entering the building. During dry periods with high winds, it is important to check and clean OA filters on a regular basis. High levels of airborne particulates indoors are often associated with increased illness. High-quality return air filters need to be installed and replaced on a regular basis to help maintain a clean indoor environment.

Combustion safety problems related to ventilation and space depressurization should be avoided by making sure that:

- Exhaust air flows do not exceed OA flows for the building as a whole.
- Mechanical rooms and other zones with combustion appliances do not operate at negative pressure. If return leaks from air handlers or ducts are depressurizing the CAZ, take steps to seal the return leaks or add supply air to bring the space to neutral or positive pressure.

VENTILATION MAINTENANCE GUIDANCE

Maintenance	Description
	Monthly or As Needed
Damper and drive	Inspect dampers and drive assemblies to verify damper stops are correct. Verify damper stop is 100% closed when no ventilation is required. Lubricate according to manufacture recommendations. Adjust drive actuator, linkage, and dampers as needed. For more details on HVAC O&M practices, refer to ASHRAE Standard 180-2008.
Filters and screens	Inspect air filters and replace based on inspection, or measured static pressure across filter. Intake screens should be clean and mechanically secure.
Rain louver	Inspect the louvers of OA intakes to be sure they prevent wind-driven rain from entering. If rain sometimes enters the OA intake duct, a section of sloped duct can be placed at the intake in a way that allows water to drain to the outside.
Exhaust operation	Help avoid building depressurization by turning off exhaust when not needed. Verify shutdown occurs as scheduled.
Ventilation effectiveness	Use handheld device to measure CO_2 in different zones and use as an indication of proper ventilation.
	Annually
Ducts	Inspect duct connections for leakage. Seal leaks with mastic. Inspect duct mechanical hangers. Repair as needed.
Measure outside air	A Testing and Balance firm should set OA amounts as required if no record exists, or after any system repairs, building modification, or change in occupancy has occurred. Damper position stops should be clearly marked.
Source contamination	Verify that the intake is at least 25 feet from any potential source of pollutant or odor source such as exhaust discharge, sewer vents, transportation loading areas, gas combustion vents, and cooling towers.
Building pressurization	Measure CAZ pressure compared to outdoors during typical building operations (with little or no wind) to verify that the CAZ does not operate under negative pressure. If CAZ depressurization exists, repair return leaks, add supply air, or otherwise bring CAZ to neutral or positive pressure.
Over/under ventilation	Consider building ventilation testing by a building scientist, or duct tightness tests when difficulty in controlling ventilation persists.

EXHAUST FAN MAINTENANCE GUIDANCE

Maintenance	Description
	Monthly or As Needed
Belts	Inspect and tighten or change as needed.
Motors and fans	Lubricate bearings according to manufacturer recommendations. Tighten motor mounts. Check pulley revolutions per minute (rpm).
	Annually
Duct	Inspect duct connection to exhaust unit. Inspect duct connections for leakage. Seal leaks with mastic. Inspect duct mechanical hangers. Repair as needed.
Fan housing	Inspect housing mounts for proper fastening to roof curbs or other structure.

Comfort Controls

Comfort controls are devices such as thermostats and ventilation controls intended to maintain a desired temperature and air quality. This section discusses sensors and their limitations in controlling comfort, followed by a brief summary of comfort controls operations and maintenance practices.

Background and Issues

Air is generally regarded as a simple invisible gas, but it is actually a complex mixture of gases, water vapor, and particles having thermal energy. The condition of air determines how comfortable and healthy the environment is for people. HVAC systems can and often do control a variety of indoor environmental factors including temperature, levels of air contamination, and ventilation rates.

Thermostats

Thermostats control space temperature. A key characteristic of thermostats is "dead band," which is also related to the cycling rate of the heating and cooling system. Dead band is the temperature range from when the system turns on to when it turns off. Thermostats commonly operate with a dead band of 2–3°F. For heating systems, this dead band may be an adjustable value, allowing the facility manager to select a cycling rate appropriate for the type of heating system. Hydronic radiator heating with water or steam, for example, may require considerably longer cycles, since the mass of the heat distribution system and heat transfer rate from the boiler to the room air is much longer than for systems that use air distribution. The thermostat then needs to anticipate that considerable heat is stored in the piping and radiators, increasing the potential for overheating the space if the system continues to provide heat to the space without proper anticipation.

Thermostats that control space cooling normally do not have adjustable dead bands or cycle rates. One major manufacturer designs thermostats to cycle the AC system three times per hour when operating at 50% of full load (10 minutes on, 10 minutes off, 10 minutes on, etc.). Some thermostats cycle the system more often, with five or more cycles per hour. This short-cycling can cause the AC system to not dehumidify as effectively, because it takes several minutes for the cooling coil to become fully cold.

Ventilation Control

Ventilation can be controlled based on schedule or occupancy detection. To save energy and improve control over indoor RH, it is good practice to shut off exhaust fans and close outdoor air dampers during unoccupied periods. Occupancy detection can be achieved by occupancy sensors or by carbon dioxide detectors, either of which can activate the ventilation systems when it detects occupants in the building. Carbon dioxide control will save more energy because the ventilation will not activate until a sufficiently large number of people are in the building, raising indoor carbon dioxide levels to approximately 1000 parts per million (ppm).

Comfort Control Operation

Temperature Control

The following measures can help control temperature:

- **CONSIDER TURNING OFF THE HVAC SYSTEMS AFTER BUILDING OCCUPANTS HAVE LEFT FOR THE DAY.** This practice includes adjusting the temperature setpoints and shutting down the exhaust and OA flows.
- **ADJUST THE PROGRAMMING OF THE THERMOSTAT OR AUTOMATION SYSTEM** to initiate system start-up sufficiently early in the morning, so that the building can return to acceptable comfort conditions by the time the work day begins.
- **EXAMINE SOURCES OF HEAT OR COLD THAT MIGHT AFFECT CONTROL**, if temperature control complaints are reported. Re-calibrate thermostats in these areas.
- **AVOID LOCATING THERMOSTATS ON EXTERIOR WALLS,** where the sun can shine on the controller, or near heat-generating office equipment.
- **CONSIDER USING LOW-COST TEMPERATURE AND RH DATA LOGGERS** to track indoor conditions at the thermostat and at other locations within the space over a several-day or longer period. This will allow detection of temperature variations across the space and through time.

Control of Ventilation and HVAC

- **SHUT DOWN EXHAUST FANS WHEN THE BUILDING IS UNOCCUPIED.** Shut outdoor air dampers, to fully closed or mostly closed, during unoccupied periods.
- Use a **BATTERY BACK-UP** for clocks used to control HVAC equipment to maintain correct time during power outages.

COMFORT CONTROLS MAINTENANCE GUIDANCE

Maintenance	Description
	Daily
Sensor	Verify that space conditions are maintained within reasonable expectations. Investigate wall thermostats for exposure to sources of heat or cold.
	Quarterly
Clock schedule control	Check clocks and adjust time as needed.
Space condition trending	Record hourly temperature and relative humidity for a typical week during different seasons to verify conditions are maintained as expected. If building system doesn't have equipment to do this, small loggers can be purchased for this task (price about $80).
Heating/ cooling system performance	Use loggers placed at a return and one at a supply to evaluate temperature difference across heat exchangers, and the delivered supply air temperature.
	Annually
Thermostats, occupancy sensors, and CO_2 sensors	Calibrate control sensors according to manufacturer specifications. Replace or calibrate sensors that perform outside the manufacture specifications. Use high accuracy sensors when replacement is needed.

HEALTH AND SAFETY

Health and safety are the highest priority in any operations and maintenance program. Many aspects of HVAC operations and maintenance affect health and safety, either directly or indirectly, as discussed throughout this chapter. This section discusses two important areas of concern: mechanical rooms and combustion safety.

Mechanical Rooms

A mechanical room houses HVAC equipment. Sometimes, non-HVAC items are also stored in them, which, in some cases, detrimentally affects air quality. Mechanical equipment in this space can also have unintended impacts on air quality and safety. This section covers some of the complex interactions that may affect health and safety, and it concludes with operations and a chart on maintenance guidance.

Background and Issues

Field research has found that air distribution systems, including ductwork, plenums, and AHUs, experience large amounts of duct leakage, as discussed previously. These leaks are often drawn from the mechanical room in which the AHUs are located.

Air distribution system leakage can create energy waste and indoor air quality problems through three ways that have implications for mechanical rooms:

- **AIR DISTRIBUTION SYSTEM LEAKAGE CAN TRANSPORT POLLUTANTS FROM A CONTAMINATED SPACE INTO THE CONDITIONED SPACE.** If zones that contain AHUs or ductwork contain air contaminants, those pollutants will almost certainly be delivered into the conditioned space. For this reason, mechanical rooms must be kept clean and dry. Standing water can lead to growth of mold, bacteria, or algae, especially if it comes into contact with dirt or soft building materials. Do not store chemicals, wet mops, or full mop buckets in mechanical rooms. These materials should be located in a janitorial closet with an appropriate sized exhaust fan. Mechanical rooms below grade may have mold and musty odors, because of contact with cold soil and elevated levels of radon, each of which can be transported to the conditioned space.
- **AIR DISTRIBUTION SYSTEM LEAKAGE CAN PRODUCE SPACE DEPRESSURIZATION THAT CAN CAUSE THAT SPACE TO DRAW CONTAMINANTS INTO THE BUILDING.** Return leaks can produce depressurization of the mechanical room, which can draw radon, sewer gases, and combustion gases into the mechanical room. These will, in turn, be drawn into the air distribution system and into the conditioned space. If the space pressure becomes sufficiently negative, sewer gases may be drawn from drain traps, especially if there is little or no water in the trap.
- **AIR DISTRIBUTION SYSTEM LEAKAGE CAN PRODUCE SPACE DEPRESSURIZATION THAT CAN ACTUALLY GENERATE AIR QUALITY PROBLEMS.** Return leaks may cause depressurization of the mechanical room or other spaces in the building. This depressurization can transport high moisture content air (especially during hot and humid weather) into interstitial cavities. Moisture build-up in building materials can lead to mold growth, and spores and mold odors can then be transported into the building. This depressurization can, if the level of depressurization is sufficiently aggressive, also cause large rates of carbon monoxide generation (see below).

Operations

To prevent health and safety problems related to mechanical room operations:

- **KEEP MECHANICAL ROOMS CLEAN:** Mechanical rooms that contain AHUs should be kept clean and dry, because the air in those rooms is also transported through leakage to the conditioned space. Make sure that air conditioning condensate is captured and drained.
- **CHECK MECHANICAL ROOM PRESSURE:** Using a manometer, measure the pressure in the mechanical room with reference to the interior spaces of

the building and also with respect to outdoors. If the room is operating at a negative pressure compared to outdoors, take steps to bring the room to neutral or positive pressure. Sometimes mechanical rooms are built to be part of the return air system and are therefore intentionally depressurized. If depressurization is creating problems, it may be necessary to hard-duct the return directly to the AHU.

- **SEAL RETURN SIDE AIR LEAKAGE:** While sealing all duct leakage is good practice, it is especially important for mechanical rooms that may have mold and musty odors, vented combustion appliances, or radon in soil below a mechanical room.

Combustion Safety

Background and Issues

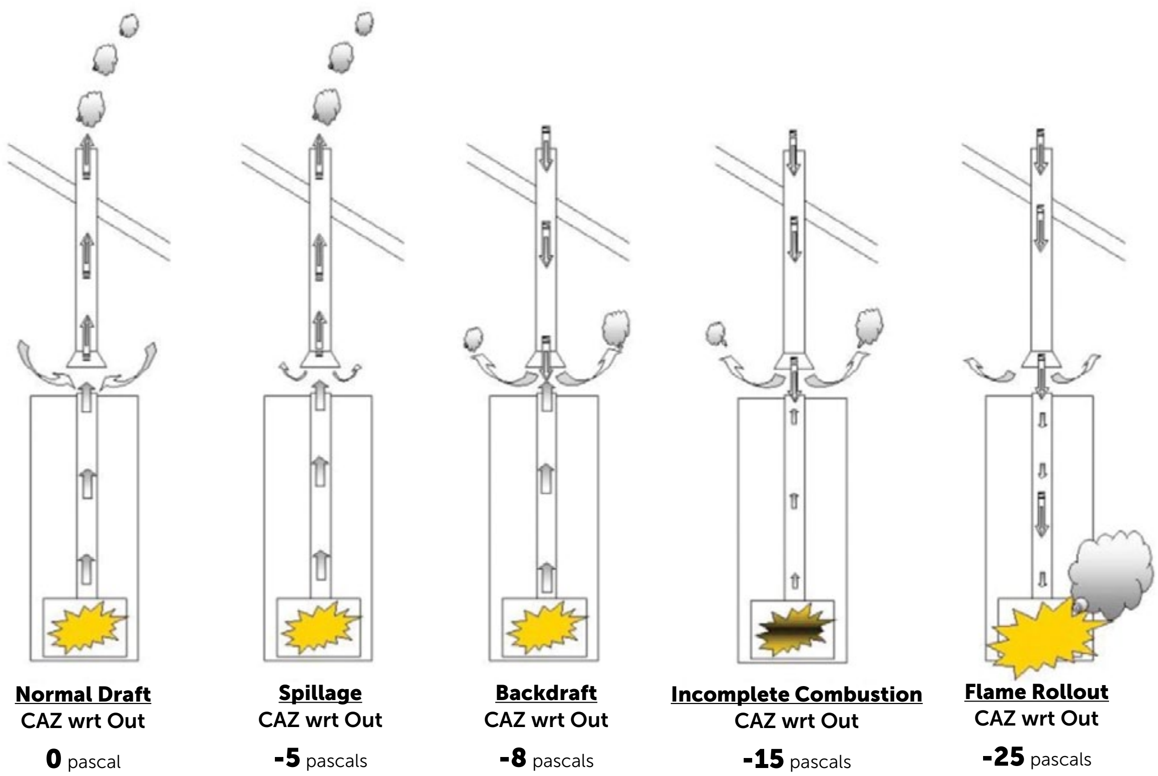
Vented combustion devices, such as gas water heaters, gas or oil furnaces, and gas or oil boilers, produce combustion byproducts such as carbon dioxide, carbon monoxide, water vapor, nitrogen oxides, small diameter particulates, and other products. In large part, these effluents are dangerous to human beings. Therefore, it is important that they are vented to outdoors. In many cases, proper venting depends upon the buoyancy of the hot gases to move them upward through a vent and successfully deliver them to outdoors. This buoyancy is a relatively weak force and can be easily overcome by negative pressure in the combustion appliance zone (CAZ). Four stages of space depressurization impact should be considered and avoided (Figure 5):

- **SPACE DEPRESSURIZATION OF AS LITTLE AS -3 TO -5 PASCALS** can induce a phenomenon called "spillage," where only a portion of the combustion byproducts are captured by the venting system. In this case, a portion of the byproducts spills into the CAZ.
- **SPACE DEPRESSURIZATION OF AS LITTLE AS -5 TO -8 PASCALS** can produce "backdrafting," where the combustion appliance vent reverses direction of flow. In this case, all of the byproducts spill into the CAZ. With either spillage or backdrafting, the combustion gases and particulates will, in many cases, be drawn into the air distribution system (through leaks in return ducts and AHUs) and delivered to the conditioned space. With fuels such as natural gas or propane, there may be relatively little odor to alert building occupants to the presence of carbon monoxide and other dangerous combustion byproducts.
- **SPACE DEPRESSURIZATION IN THE RANGE OF -15 TO -20 PASCALS** can create a particularly dangerous circumstance of "incomplete combustion." The relatively strong negative pressure in the CAZ causes air to flow downward through the vent at a high velocity. This airflow discharges from the

vent onto the top of the water heater or other combustion device, impinging upon the discharge of the appliance flue (which is the vent inside the combustion appliance). The flue continues to vent upward into the room, but with reduced airflow. This reduced rate of airflow in turn slows the entry of combustion air into the combustion chamber of the water heater. With insufficient combustion air, the appliance that might otherwise produce little carbon monoxide (say, in the range of 10 ppm) might suddenly produce very large amounts of carbon monoxide (perhaps in the range of 50,000 ppm). These high levels of carbon monoxide can lead to carbon monoxide poisoning and even death to building occupants.

- **SPACE DEPRESSURIZATION IN THE RANGE OF -20 TO -25 PASCALS AND GREATER** can produce flame rollout. In this circumstance, the air velocity downward through the vent impinges on the appliance flue with sufficient

FIGURE 5. COMBUSTION SAFETY PROBLEMS CAUSED BY DEPRESSURIZATION OF THE COMBUSTION ZONE



Negative air pressure in combustion appliance zones interferes with drafting of atmospherically vented appliances. This can result in minor to dangerous conditions depending on the level of depressurization.

Source: Florida Solar Energy Center

force to reverse the direction of airflow in the flue itself. When the appliance cycles on, the gas ignites but the flame does not remain inside the combustion chamber. Rather, the flame is pushed out of the combustion chamber by the air moving down the flue. Some portion of the flame then burns outside the appliance, creating the likelihood that materials around the water heater will ignite.

Some combustion appliances have venting systems that resist the effects of space depressurization. Sealed combustion appliances are not atmospherically vented. Combustion air is delivered into the appliance from outdoors, which is not affected by the pressure field in the CAZ. Power draft equipment is also largely unaffected by space pressure. A fan is used to push the combustion gases from the building. In most cases, the fan has sufficient power to overcome the effect of CAZ depressurization.

As indicated in the Air Distribution System section of this chapter, duct leaks (especially return leaks) in mechanical rooms must be sealed to avoid depressurization. However, even when they are sealed, space depressurization is still possible.

For example, simply removing the filter access panel can produce substantial levels of space depressurization. If a maintenance person fails to replace that panel, a dangerous level of negative pressure could persist in the CAZ. It is also important that exhaust fans do not operate in mechanical rooms, unless it is verified that their operation does not significantly affect pressure in that space.

Combustion appliances typically require combustion and dilution air from the space. The National Fuel Gas Code, known as standard NFPA 54, defines requirements for venting to provide the necessary levels of combustion and dilution air. The vents must remain unobstructed in order to allow the necessary air into the CAZ. Therefore, equipment, boxes, and other items should never be placed in front of the combustion and dilution air vent openings.

MECHANICAL ROOM AND COMBUSTION SAFETY MAINTENANCE GUIDANCE

Maintenance	Description
	Daily
Storage in mechanical room	Implement a policy of limited storage. Inspect and remove stored cleaning materials or other chemicals. Avoid storing combustible materials nearby any combustion appliance.
Mechanical room–clean and dry	Clean the mechanical room before dirt/dust levels build up. Remove wet materials immediately and determine cause and solution for wetness.
Carbon monoxide (CO)	Make sure CO detectors are located in CAZ and are functional. Designate responsibility to staff to be aware of alarms.
	Quarterly or After Any Service Work Done in Mechanical Room
Combustion/dilution air	Verify that combustion/dilution vents' size and installation comply with the construction building documents or with the National Fuel Gas Code (standard NFPA54) for all gas appliances located in the CAZ.
Avoidance of room depressurization	Measure mechanical room and CAZ pressure with reference to outside and take action to neutralize depressurization beyond -3 pascals. Inspect AHU panels for leakage. Seal leaks with UL approved tapes and putty. Seal return duct leaks in CAZ or mechanical rooms with mastic. If CAZ is still depressurized, add some supply air into the CAZ or replace natural draft appliances with sealed or forced-draft combustion appliances. Measure CO levels in CAZs or test CO monitor in room.
Wall moisture	Spaces below grade should have wall inspections to look for signs of moisture or mold. Damp external walls signify serious moisture control problems requiring immediately professional assessment.
	Annually
Radon	Conduct a radon test. Consult EPA guidelines on required action and frequency of follow-up testing based on initial test results. Generally seal all ground floor and below-grade penetrations. Note that some plumbing and electric penetrations are located inside wall cavities.
Review list of combustion appliances	Place all natural-drafted combustion appliances on list of equipment for high-priority replacement. Replace with sealed combustion or power-draft equipment. Energy Star gas appliances generally use sealed combustion venting, and yield reduced energy consumption and improved air quality control.
Carbon monoxide	Consider measuring CO in the combustion flue. Have appliances serviced by qualified person if vented CO concentration exceeds 50 ppm or if CO detector alarm is tripped. Replace CO detector batteries annually or at manufacturer's suggested schedule. Review with all staff or new hires, proper procedure for investigating alarms, alerting emergency professionals when needed, and evacuation.

LIMITING LOADS FROM DEVICES BROUGHT IN BY EMPLOYEES

Employees may bring electrical devices with a wide range of power usage into the facility. These devices may include desk lamps, table fans, and space heaters. Without a plan or policy in place, these devices can hamper energy conservation efforts and possibly create environmental hazards.

Impact of Devices

Some devices brought in by employees use relatively little energy, while others consume considerable energy and may also represent a fire hazard. Building operations and maintenance personnel often ignore such devices unless they interfere with the proper operation of the system. In general, these devices have the potential to significantly increase the building's energy consumption. Limiting use of unnecessary electric devices will not only conserve energy used by the device itself, but also reduce the space conditioning load.

Employee Personal Device Guidance

To deal with these devices:

- **CONDUCT A BUILDING SURVEY TO IDENTIFY HEATING OR COOLING DEVICES BROUGHT IN BY BUILDING OCCUPANTS,** which may indicate they have additional heating or cooling needs.
- **RECOGNIZE NO SINGLE SET OF INDOOR CONDITIONS IS COMFORTABLE FOR EVERYONE.** People have different metabolic rates and levels of clothing. Additionally, space conditions often vary from one location to another within a building or zone. Thus, some requests for supplemental space conditioning devices are valid.
- **IN THE CASE OF SUPPLEMENTAL SPACE CONDITIONING DEVICES (E.G., SPACE HEATERS), IDENTIFY THE CAUSE OF THE COMPLAINT THAT LEADS TO BRINGING THE DEVICE TO WORK.** If the space is too cold during the summer, try to adjust the space temperature at that workstation to accommodate the employee's or occupant's comfort needs. If the space is too cold during the winter, see if supply airflow can be increased to that work area. Alternatively, try to modify cold envelope features (e.g., nearby windows, poorly insulated walls, or drafts) to improve localized comfort.
- **SET GUIDELINES FOR SUPPLEMENTAL DEVICES** (maximum wattages, safety ratings, etc).

Table 2 provides examples of such devices and the relative amount of power each consumes. Keep in mind that some devices consume energy even when turned off or not in use. One clue that a device may be using energy even after it is turned off is to feel for warmth at the power supply or on device. Examples of policies to consider are in the far-right column, although it is generally more effective to obtain input from and buy-in by staff occupying the space before setting new policies.

TABLE 2. EXAMPLES OF PERSONAL DEVICES AND USAGE POLICIES

Equipment	Relative power (Approx. wattage)	Example Policy
Battery chargers (small electronics)	Low (15W–30W)	Unplug when not used.
Radio	Low (40W)	Unplug when not used.
Desk lamp	Low–medium (40W–100W)	Turn off when not used. Limit lamp to appropriate wattage and use high efficiency bulbs when practical.
Personal size floor fan	Low–medium (20W–60W)	Turn off when leaving space. Consider controlling by occupancy sensor. Limit fan size to that appropriate for space. (Example: 6”-8” diameter fan for single workspace at desk).
Oscillating circulation fan	Medium–high (30W–60W)	Turn off when leaving space. Limit to task areas more open that require movement within space or more than one person in area.
Personal space heater	High–very high (150W– >500W)	Discourage use, but allow in cases where existing heating is inadequate for personal needs. Permit only heaters with tip over safety shut-off. Have users sign a “safe- use” policy agreement that also establishes a max. watt limit appropriate for each space. *(Example: small workspace limited to 300 watts).* **ALWAYS** turn off when leaving space.
Small cooking appliances microwave, hot plates, toaster oven	Very high (>500W)	Limit to single appliances that can be shared.
Small personal space cooling (self-contained units or window AC)	Very high (>500W)	Low probability employee will bring in personal AC. If installed, make sure condensate can be properly drained without leaking or spilling. Waste heat must be properly vented to outdoors. Turn off when leaving space.
Small refrigerators	Medium (150W but cycles)	Encourage group sharing of one larger refrigerator, which consumes much less energy than several small units.

EQUIPMENT REPLACEMENT OR UPGRADES

Many public housing buildings were built more than 30 years ago when energy was still considered inexpensive. There is, therefore, great potential for energy conservation by upgrading to more efficient choices when replacing cooling and heating equipment or when considering alternative energy systems.

Replacing Cooling Equipment

Cooling equipment will be replaced for various reasons from time to time. Some equipment will have reached the end of its useful life. Replacement could also be prompted by the need for improved system reliability. When replacing equipment, energy efficiency should be a major consideration, not only because of the environment, but also because it may be the most cost-effective choice.

In the past few decades, the energy efficiency of AC systems has increased dramatically. Units purchased prior to 1991 typically had SEER ratings in the range of 6 to 8. During the 1990s, AC system efficiency gradually increased. A major step forward occurred in 2006, when the minimum SEER rating that could be manufactured was raised from 10 to 13. The availability and cost of very high efficiency split DX equipment, in the 15–17 SEER range, has improved substantially with rebates available through manufacturers, utilities, and federal programs. The efficiency of chillers has also improved substantially. Variable-speed, variable-capacity chillers that can provide super high efficiency under part load are now on the market. Some chiller units have efficiency ratings as low as 320 Watts per ton at 50% or lower load factor, which is as much as 50% lower energy use compared to standard new chillers.

Energy efficiency heavily influences the lifecycle cost of cooling systems. Consider the first cost and total energy cost of two AC systems (see Box 2). The cost of a replacement five-ton SEER 13 AC system might be $6,000, compared to $9,500 for a SEER 21 unit. In some cases, utility or government incentives may narrow the price differential. If the unit operates for 1500 hours per year and the cost of electricity is $0.11 per kWh, it will take 12 years for the energy savings from the SEER 21 unit to pay for the added cost.

BOX 2. HOW TO ESTIMATE SAVINGS BETWEEN SEER 13 AND SEER 21 60,000 BTUH (5 TON) SYSTEMS

SEER 13: 60,000 Btuh/13 Btu/w = 4.615 kWh/hr x 800 hours x $0.11/kWh = $406 per year

SEER 21: 60,000/21 = 2.857 kWh/hr x 800 hours x $0.11/kWh = $252 per year

Difference = $154 per year

Installing Higher Efficiency AHUs, Fan Motors, and Variable Speed Drives

Energy efficiency improvements can also be achieved by means of higher efficiency fans and fan speed controllers. In the past decade, variable-speed AHUs (using electronically commutated fan motors) have become widely available. By themselves, these higher efficiency fan motors can increase AC and heat pump SEER rating by 1 point, e.g., from SEER 13 to SEER 14. They also save considerably on electricity costs of furnace operation. When installed with properly sized (or oversized) duct systems, they can achieve substantial energy savings in and of themselves compared to conventional shaded-pole motors.

AHU fans in larger commercial-sized systems can also be modified to operate much more efficiently using variable frequency drives (VFDs). VFDs adjust fans to a lower fixed airflow rate. They can also be used to vary AHU airflows in real time in response to temperature offset from thermostat setpoints or in response to VAV box damper settings. Benefits include 1) reduced fan power, 2) less potential for overcooling of the space and concomitant need for reheat, and 3) extended life of the air-moving equipment and filters.

Exhaust fans can also benefit from VFDs. If exhaust airflow rates are found to be larger than required, then an installed VFD can lower the exhaust fan airflow rate. This can reduce exhaust fan energy use and shrink ventilation-related heating and cooling loads.

Replacing Heating Equipment

Whether replacing electric or gas heating systems, PHA buildings can become more energy efficient.

Electric Heating Systems

Electric resistance heating, used in some PHAs, is very energy inefficient. Many higher efficiency heating equipment options are available. When selecting electric heating systems, consider heat pumps, which are about 3 times more efficient than electric "strip" heat in the southwestern region.

Heat pump efficiency can be compared by heating seasonal performance factor (HSPF) or coefficient of performance (COP). Higher numbers indicate higher efficiency. Heat pumps are very suitable for cooling-dominated climates, although the need remains to have properly sized back-up strip heat for the periods when outdoor air temperatures become very cold. It is more efficient to lock out strip heat so it cannot come on until outdoor temperatures fall to 35°F or cooler. This will ensure that strip heat does not operate during transition from night setback temperature to daytime setpoints. If a gas system is being replaced by an electric heating system, additional electric service work may be required if the existing electric service panel does not have sufficient capacity.

Gas Heating Systems

Gas equipment efficiency is measured by the annual fuel utilization efficiency (AFUE). The minimum AFUE currently allowed for new equipment is 78%, which means 78% of the fuel energy gets transferred to useable space heat and the other 22% is lost up the chimney. The highest efficiency gas furnaces can achieve efficiency in the range of 90–95% by extracting energy from the water vapor contained in the combustion byproducts. This is why they are also known as condensing furnaces. The exhaust of these systems must be vented according to manufacturer guidelines since the condensed exhaust is acidic and will damage certain materials. Old unlined chimneys or metal vent systems of older equipment should not be used for condensing furnaces.

Alternative Energy Systems

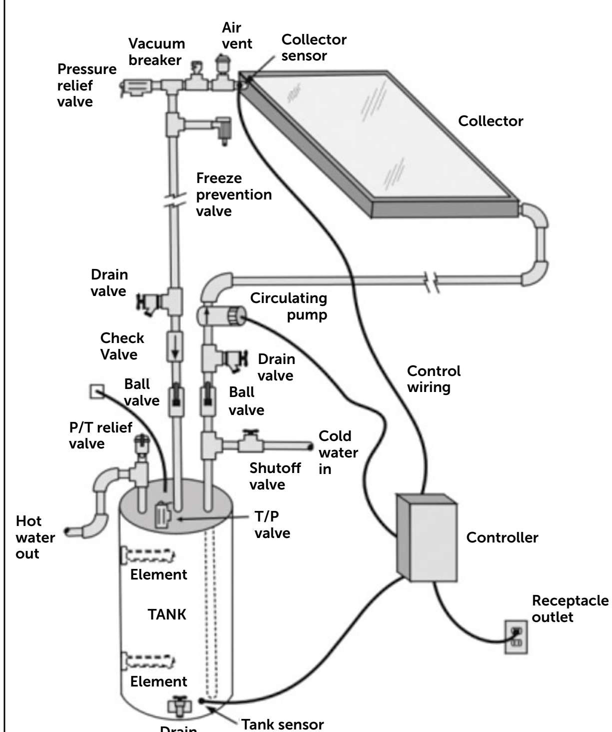
As energy costs and the awareness of limited fossil fuel resources increase, there is a growing desire to use alternative energy resources that have little or no carbon footprint. This section discusses solar thermal and solar electric systems, each of which can be used as a renewable energy source for buildings.

Solar Thermal Systems

Solar thermal systems can use solar energy to heat domestic hot water (DHW). The system consists of a solar collector, piping to transfer hot water to a storage tank, and some form of back-up heat (Figure 6).

In PHA common areas, the systems can be sized for small applications that use very little hot water, such as office or public restrooms. They can even be used in residential facilities but they are typically more cost-effective in large use applications, such as hot water for clothes washing. An engineer must first determine site suitability, which includes available space for collectors, orientation to the sun, potential for shading of collectors, and available space for hot water tanks. Maintenance will involve confirming that the circulation pumps are working (through weekly inspection), repairing plumbing leaks that may occur, and cleaning collector surfaces during extended periods without rain.

FIGURE 6. ACTIVE SOLAR THERMAL SYSTEM



Source: Florida Solar Energy Center

In the Southwest, where the wintertime solar radiation is high, solar can provide cost-effective space heating as well. Systems that meet 100% of the DHW and perhaps 40-50% of the building's space heating needs can also be cost-effective, depending upon the cost of fuel and solar incentives. For this application, the collectors will be tilted more steeply toward the south to optimize solar collection during winter months. Solar systems can also be cost-effective for pool heating.

Solar Electric Systems

Crystalline modules mounted on a sloped roof.
Source: Florida Solar Energy Center

Thin film modules mounted on a flat roof. This flat-roof type is generally less efficient and requires more roof area than a sloped system.
Source: Florida Solar Energy Center

Solar electricity is produced by photovoltaic (PV) panels commonly installed on a roof. In typical systems, the direct current produced by the panels is converted to alternating current using an inverter and then delivered into the utility grid. If the PV system is producing more energy than the building is consuming, then the electric meter in effect runs backward.

Just as in solar thermal systems, an engineer must evaluate the useable area of the roof and consider limiting factors such as shading and weight load imposed on the roof by solar collectors. PV system performance is drastically affected by shading, since shade over just 10% of the panel surface area can result in 90% reduction of power output in some configurations. In 2010, PV systems cost around $7–8 per installed Watt of capacity, and prices are expected to drop substantially in the coming years. State and federal sources may offer incentives to reduce system cost. While the life of the solar panels may be 20 years or longer, the inverter is likely to have a life of only 5–15 years. A replacement 4000W inverter may cost $2,000 to $3,000. Solar electric systems require little maintenance. The collector surfaces may need to be cleaned during extended periods without rain.

Even though the solar resource available in the southwestern region is some of the best in the world, building energy efficiency still normally produces a better return on investment than solar energy. The priority should be to optimize the energy efficiency of the building envelope and HVAC systems, and then consider implementing renewable energy production. On the other hand, societal and environmental costs and consequences related to fossil fuel extraction and consumption are often not accounted for in building site financial analysis.

ACRONYMS IN THIS CHAPTER

AC	Air conditioning
ADS	Air distribution system
AFUE	Annual fuel utilization efficiency
AHU	Air handler unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTU	British thermal unit
BTUH	British thermal unit per hour
CAZ	Combustion appliance zone
CDD	Cooling degree days
Cfm	Cubic feet per minute
DDC	Direct Digital Control
DHW	Domestic hot water
DOE	Department of Energy
DX	Direct expansion
EPA	Environmental Protection Agency
FEMP	Federal Energy Management Program
HDD	Heating degree day
HVAC	Heating, ventilation, and air conditioning
kWh	kilowatt hour
MERV	Minimum Efficiency Report Value
NAIMA	North American Insulation Manufacturers Association
NGFA	National Fuel Gas Code
OA	Outdoor air
PHA	Public Housing Authority
Ppm	Parts per million
Psig	pounds per square inch gauge
PTAC	Package terminal air conditioner
PV	Photovoltaic
RH	Relative humidity
RTU	Rooftop package unit
SEER	Seasonal energy efficiency ratio
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
VAV	Variable air volume
VFD	Variable frequency drive