APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Energy-Efficient Operations and Maintenance Strategies for Packaged HVAC Systems

Summary

Packaged HVAC systems are used in almost all classes of commercial buildings. They function in harsh outdoor environments, and often with no on-site staff responsible for their operation, so that they get no attention until they break down.

The main purpose of regular maintenance is to keep equipment in good working order. It also keeps it running at optimal efficiency, though realistically this is often considered a secondary benefit. This Application Note focuses on specific operation and maintenance strategies that relate to energy efficiency.

To avoid wasting energy, equipment must be kept clean, adjusted, and properly charged with refrigerant. Air leaks should be minimized. Controls should be managed with the goal of reducing run-time. A good maintenance program carried out by in-house personnel or a service contractor can help ensure that efficient maintenance strategies are performed regularly.

How Operations and Maintenance Strategies Save Energy

Packaged HVAC systems consist of various configurations of pre-assembled, off-the-shelf equipment for space heating, cooling and ventilation. Used in almost all classes of commercial buildings, they are especially suitable where performance requirements are less demanding and low initial cost and simplified installation are important.

The energy-efficient strategies in this Application Note focus on single-package rooftop units, but many apply to split-systems and package terminal air conditioners as well.

Figure 1 shows a typical packaged rooftop HVAC unit. A supply fan and filter section provide air to the conditioned space, and a mechanical cooling system consisting of a compressor, ***evaporator coil***[1], and ***condenser coil*** rejects heat to the outdoors. Most units are available with an ***economizer*** for "free cooling." It may also have a heating section, typically a gas burner.

Regular maintenance saves energy by keeping packaged HVAC units running at optimal efficiency. Following are some things that can degrade performance:

- **Dirty condenser coil and evaporator coil** reduce cooling capacity and make the compressor work harder and longer.

- **Improper refrigerant charge** results in inefficient compressor operation.

- **Dirty filters and dirty fan blades** increase static pressure and reduce airflow, reducing efficiency and capacity.

- **Air leaks in cabinet and ducts** waste conditioned air, reducing system efficiency and occupant comfort.

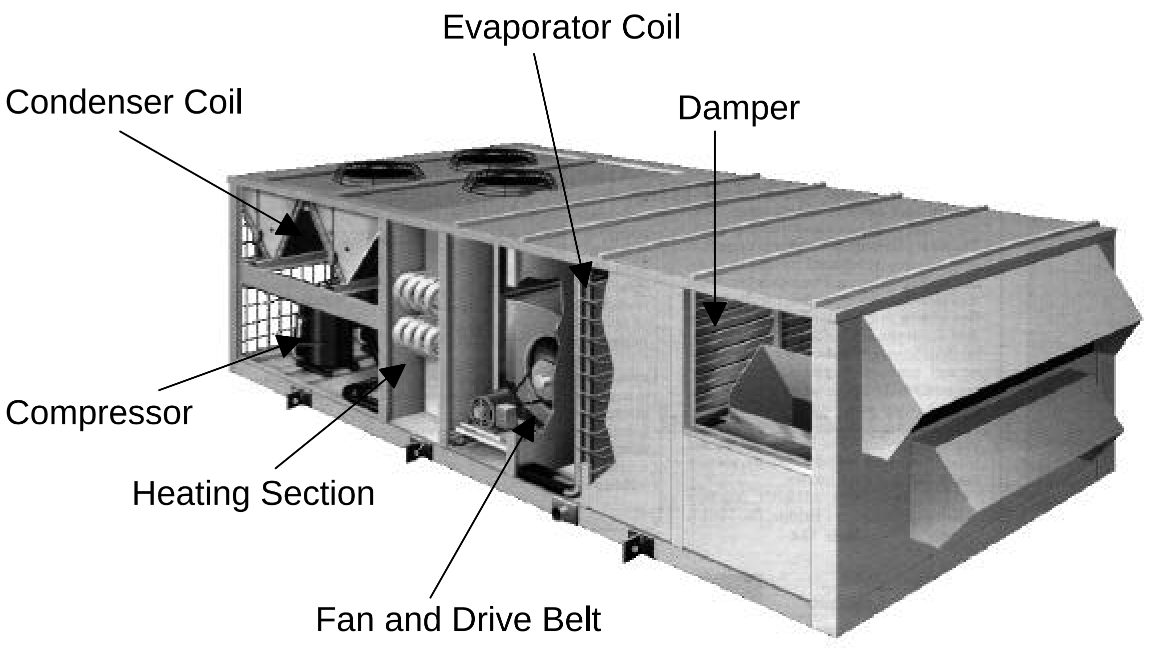

Figure 1: Typical Packaged Rooftop Equipment *(Source: York)*

[1] Bold-Italic words are defined in the section titled Definition of Key Terms.

- **Improper belt alignment and adjustment** reduces fan drive efficiency.

- **Dirty heat exchange surfaces** and improperly adjusted combustion controls decrease heater efficiency.

Operational strategies are things the owner can do to control the HVAC system. For example, thermostat setpoints affect how much work it is asked to do, and the operating schedule determines how long it must work.

Setting up an operations and maintenance (O&M) program can help assure that efficient operational and maintenance strategies are performed regularly.

Energy Saving Operations and Maintenance Strategies

If packaged HVAC equipment is not regularly maintained it will lose efficiency and eventually fail. The manufacturer's recommendations should be followed. This Application Note focuses on important but often overlooked strategies; for informative "how-to" details and tricks of the trade, see References 3, 4 and 5.

Routine Maintenance Strategies

In general, air-side maintenance and repairs should be done first: problems here are common, and most refrigeration problems can't be fixed effectively without proper air flow. (For example, refrigerant charge measurements will be erroneous if air flow is restricted by dirty filters).

Clean Evaporator and Condenser Coils

Dirt on evaporator coils reduces system air flow and directly degrades the coil's heat transfer efficiency, significantly cutting cooling capacity. With good filtration, the unit's evaporator coil will stay fairly clean. The evaporator coil should be inspected at least once a year to make sure the filters are doing their job.

The condenser coil, exposed to unfiltered outdoor air, suffers much greater degradation due to dirt. Cleaning it is one of the most cost-effective steps available. A dirty coil that raises condensing temperature from 95° to 105°F cuts cooling capacity 7 percent and increases power consumption 10 percent, with a net (compressor) efficiency reduction of 16 percent. In a 10-***ton*** unit operating 2,000 hours a year this wastes about $250 per year in operating costs. A technician can clean the condenser in about an hour, which typically costs about $50; in this example payback takes just over two months and brings net annual savings of $200.

Fix Leaks in Cabinet and Supply Duct

Annual checkups should include a survey of air leaks and corrective action such as replacing screws or latches, and patching or replacing gaskets. Cabinet and duct integrity is particularly important on the supply-air side, where high pressure can force a lot of air out a small crack. Losing only 200 cfm from a 10-ton rooftop unit cuts cooling and air flow capacity about 5 percent and wastes more than $100 per year in energy costs.

Clean and Adjust Dampers

Perhaps the most common packaged system malady is improper ***damper*** operation. Dampers operate in a continual flow of dirty air that fouls pivot points and actuator mechanisms (a coarse prefilter only keeps out leaves and birds). A study of 13 units found not one with properly operating outside-air dampers; this can have major energy consequences and seriously impact indoor air quality.

Operating properly, dampers keep the compressor from running when outside air temperature is below about 60°F. But unless they are kept clean and well-lubricated they stick, robbing the unit of free cooling potential (if closed) or overloading the cooling coil with too much hot outside air (if open).

During servicing, moveable surfaces should be cleaned and lubricated. As long as a service technician is on the roof, this should take about 15 minutes and cost $10. If this turns off one five-ton compressor just 100 hours, it will save 450 kWh ($45 at 10¢ per kWh).

After cleaning and lubrication, a damper should be run through its full range. Tools can generate electrical control signals to drive the actuator, or the economizer setpoint can be manipulated at the control panel. Afterward the setpoint should be checked.

Fan, Bearings and Belts

Impeller blades on a forward-curved fan can fill up with dirt, lowering efficiency. Good filtration helps keep dirt out, but an annual visual inspection should still be performed. Cleaning the blades on a small fan takes an hour or more; cleaning larger fans, especially those with multiple wheels on a single shaft, can be a major project.

Many HVAC technicians have found fan motors running in the wrong direction. Because they still supply perhaps 50 percent of rated flow even running backwards, this may not be readily apparent. The most common cause is switched wire leads on the motor. Clear labels on the fan housing, pulleys, motor, and wires can help prevent this problem.

Newer fans have self-lubricating bearings (sealed-cassette ball bearing cartridges preloaded with grease); when they finally fail, typically after several years of service, the bearing cassette must be replaced. Signs of impending failure are excessive noise, vibration, or heat emanating from the bearing.

Fans in older rooftop units have sleeve bearings, oiled metal-to-metal running surfaces, which should be lightly oiled two or three times a year with the recommended lubricant. A label near the bearings should indicate the lubrication interval, lubricant type, and a log of past service.

Conventional greased ball bearings are occasionally found in packaged units. Their most common problem is overgreasing, which can be as damaging as undergreasing.

Improperly adjusted belts rob the drivetrain of power, create noise, and must be replaced sooner than well-adjusted belts. Belts should be aligned to prevent lateral wear. Proper tension should be maintained; loose belts slip on the pulley wheels, causing torque loss and rapid wear. Belts that are too tight put an excessive load on the motor and fan shaft bearings, causing early failure of the bearings and/or belts.

Using notched V-belts is an easy way to improve drive efficiency by 2 to 10 percent. They run on conventional smooth pulleys, but notches on the inside of the belt reduce internal bending losses and improve grip.

Replace Filters

Filters help maintain indoor air quality, and protect downstream components of an air-handling system from accumulating dirt that cripples performance. Although complex system-wide effects result in only modest energy savings from changing filters, good filter maintenance is still important because cleaning downstream components is expensive and might not get done on a regular basis.

Avoid filters encased in "bottlecapped" cardboard with circular holes punched in it, as these reduce the effective filter area and increase pressure drop. Also avoid fiber or polyester filters with an adhesive coating—it can foul the evaporator coil.

Pleated filters made with cotton/synthetic fabrics cost more and perform better than flat filters. The fabric boosts filtration efficiency; the pleats increase effective area, reduce pressure drop, and extend useful life.

Filter changing intervals can be based on the pressure drop across the filter, or (more commonly) by calendar scheduling or visual inspection. Intervals should be between one and six months, depending on dirt loading from indoor and outdoor air. Home Depot stores, for example, change rooftop-unit filters monthly, largely because dust from the cement they stock finds its way into the return air. More frequent changes also may be required during economizer season, as outdoor air is usually dirtier than indoor air.

Measuring pressure drop is the most reliable way to rate filter loading. This requires some effort as most packaged units lack built-in pressure taps. A technician can install taps and then use a hand-held pressure meter to check filter status. In facilities with predictable and regular filter loading, pressure measurements can be used to establish the proper filter-change interval; thereafter, filter changes simply can be scheduled.

Pressure measurement taps are a bargain; they cost less than a single change of a high-quality filter. Complete air filter pressure kits which include a dial gauge cost about $70. Hardware for installing taps that can accommodate a portable gauge costs less than $10. The work can be done by a service technician in minutes.

Check Airflow

The final step in checking the air side of the system is to measure the airflow and make sure it is within the expected range (350 to 400 cfm per ton of cooling capacity). This can be difficult; Reference 5 describes a simplified technique.

Check Compressor

Most packaged equipment is very sensitive to the amount of refrigerant in the system. Overcharging or undercharging will significantly affect energy efficiency.

In an overcharged system, excess liquid refrigerant backs up in the condenser, increasing head pressure and making the compressor work harder.

In an undercharged system the evaporator is starved for refrigerant and cooling capacity is reduced. This is indicated by abnormally low pressures on both the high- and low-pressure sides of the system, frosting on the evaporator entrance, a warm suction line, a cool liquid line, warm supply air, or continuous compressor operation. Undercharged systems usually result from a leak, which should be found and repaired. This can cost from $250 to as much as $1,000 if components such as the evaporator coil must be replaced.

Electrical testing and oil analysis are the two main tests of compressor health. The tests determine whether damaging moisture or acid is present in the refrigerant system. Systems that fail these tests should be fitted with one or more filter-dryers.

Many compressor failures are preceded by an increase in case temperature. Tapes with indicator dots that turn black above a certain temperature are available in 50°F increments, cost about $1.50 each, and can be placed on the compressor discharge tubing as a diagnostic aid.

Heating Section

Components should be cleaned and adjusted for efficient operation. (Refer to the manufacturer’s procedures).

Heat Pumps

A major maintenance action for heat pumps is to check the defrost function of the outdoor coil. As heat is removed from low-temperature air passing over the coil, frost can form on the coil; if too much builds it reduces the heating capacity, resulting in excessive use of electric resistance supplemental heating and perhaps in equipment failure. Frost is removed by reversing the heat pump cycle for a short time; the coil should defrost rapidly. Problems could be caused by the timer, defrost thermostat, reversing valve, defrost relay, or wind effect.

Operational Strategies

Check Proper Operation of Thermostat

Programmable thermostats are typically used with packaged equipment to schedule occupied/unoccupied temperature setpoints and on/off periods for the fan. Override controls allow temporary use by occupants during normal “off-periods.” Settings should be checked and adjusted to prevent excessive run-time, maintain comfortable conditions during occupied hours, and achieve the maximum practical setback/setup during unoccupied hours.

Some facilities control packaged equipment with building energy management systems (EMS), which use inputs such as the temperature of the building mass to determine when HVAC equipment must be started. EMS provides the capability for additional control strategies such as optimal start/stop. The controls can also shut down the cooling or heating functions before building occupants leave.

Contract Services versus In-House Maintenance

Contracting is becoming more popular as companies focus on their core businesses. Contracts can take a variety of forms. For example, a basic maintenance contract for a 10-ton rooftop unit (three to six years old, in reasonable condition, and with easy access to the roof) costs about $150 per year. When the equipment needs more extensive servicing, calls are billed on a time-and-materials basis.

Finding a contractor of integrity is more important than finding the low bidder. (One contractor says a lot of "maintenance contracts" really are "filter-change contracts.") Owners should check references, ask for sample reports, and learn whether a contractor is committed to training technicians and equipping them properly. A thorough maintenance program includes check-ups before each heating and cooling season, at least four filter changes per year, and complete reports of technicians' findings.

In-house maintenance only makes sense for companies with at least 200,000 square feet of closely grouped facilities—enough to keep a crew of at least two technicians occupied. These employees typically handle everything from scheduled maintenance to complex troubleshooting and repairs, although repetitive tasks and very specialized tasks still may be contracted out to providers who can perform them more economically.

Advantages of in-house maintenance include the ability to integrate HVAC maintenance with other tasks (such as responding to complaints), and—if the same technicians stay over several years—the benefits of familiarity and expertise with specific units. In-house staff may be more committed than contract technicians. Training investments can yield dividends in energy savings and extended equipment lifetimes.

Recordkeeping

Managing the information collected by a thorough maintenance program is an important issue. Readings collected over time can help predict failures, dictate service needs, or verify energy performance goals, and some companies are automating recordkeeping and data collection to take advantage of this. In addition, tracking systems can indicate which units need remedial attention or replacement.

A low-tech approach is to keep folders or binders containing performance reports and measured data near the unit; they must be extremely obvious and accessible or they will not be used. Specific service instructions also can be located in this area. Other documents—original factory instructions, wiring diagrams, fan curves, component specifications, and so on—also should be available to service technicians. This simple step can save hours of time and hundreds of dollars over the life of a rooftop unit.

A few recordkeeping considerations include:

- Don't let a service contractor keep the sole copy of any performance document.

- Keep performance information as close to equipment as possible.

- Maintain a service log sheet and a record of alarm conditions for each unit.

- Unless records and containers can withstand abuse, they will be shunned. Consider reinforced, heavy-duty paper sheets and binders, and waterproof metal boxes.

- High-visibility signage encourages use of service logs and other tracking documents.

- Contracts with service providers can be written to enforce use of service logs and other tracking documents.

- Owners should demonstrate to contractors that submitted reports are indeed read.

Automated Maintenance

Most packaged units have self-contained controls, communicating only with thermostats in the conditioned space. However, facilities using EMS to control packaged equipment can speed response when problems occur. For example, if a thermostat calls for cooling for more than five minutes and supply air temperature remains above 65°F, the EMS assumes a malfunction and calls the service contractor, who can either call somebody at the site or dispatch a service technician. In many cases, the problem is solved before the customer even knows it arose.

An EMS has the added advantage of performance data trending. Sensors can be installed to measure critical temperatures, pressures, etc., and track them over time. Such data are very useful for early detection of problems.

Applicability

The strategies in this Application Note can be applied to virtually any packaged equipment. Following is a practical approach to determining which tasks are most important, based on the age of the equipment:

- **New Units (Up to Five Years):** These require only a basic maintenance contract. Regular filter changes and coil cleanings are more important than thorough diagnostics (although these will provide a useful baseline for later use). At least for the first year, use the same contractor who did the installation, since part or all of the unit is still under warranty. Many new units have a five-year warranty, or one typically can be bought at the time of installation for about 25 percent of the compressor cost.

- **Middle-Aged Units (5-10 Years):** These are out of warranty, and require more attention. A complete annual checkup is warranted, and a written report should be assembled so measured values can be compared year-to-year. Owners should consider policies for replacing or repairing components that break down (such as blower motors; should they be replaced with standard or premium efficiency models?), and may want to purchase more comprehensive service contracts.

- **Older Units (More Than 10 Years):** Owners should consider how and when to replace such units. To determine whether to do this immediately or wait for a breakdown, compare annual operating and maintenance costs to the cost of installing and operating new units. A unit should be replaced if an expensive failure (compressor burnout, condenser coil leak, cracked heat exchanger) occurs, but ideally proper replacement units should be specified well before failure. This makes performance monitoring even more important, since it can help anticipate costly problems. An equipment-breakdown insurance policy also may make sense for older units.

Field Observations to Assess Feasibility

This section suggests specific things to look for to determine whether O&M efficiency improvements are likely to be practical and cost effective.

Related to Applicability

If a customer does not have a service contractor or internal staff who routinely service the equipment, there is a high probability that many of these improvements will apply.

The general condition of packaged equipment is an indicator of how the system has been maintained, although a weathered cabinet does not necessarily mean improper service. Important signs include dirt accumulation on the condenser coil, intake louvers, and ceiling diffusers. Look for access panels to the filter section or cooling coil that do not seal properly. Look for deteriorated insulation on exposed ducts and signs of air leakage from the duct. Excessive noise is another indicator.

Check the thermostats. If internal clocks are inaccurate, schedules and setpoints are inappropriate, or separate thermostats are set differently (when they should be the same), it is a good indication that efficient O&M strategies have not been applied.

Occupant comfort problems can indicate O&M has not been performed adequately.

Related to Energy Savings

Following are some things to look for which have the greatest energy savings potential:

- **Dirty condenser and evaporator coils**.

- **Loose panels and duct leaks** which allow conditioned supply air to escape.

- **Malfunctioning controls.** PG&E's Energy Resource Center has temperature-monitoring equipment available for checking the operation of economizer controls.

- **Long operating hours** at a facility.

Related to Implementation Cost

Reliability and equipment life, rather than energy savings, are probably the main reasons customers set up O&M

programs. When the value of reliability, occupant comfort, and extended equipment life are added to the energy savings, many of these improvements will be very cost effective.

Some strategies such as automated maintenance may be cost effective only with larger equipment (20 tons or more) because of the cost of sensors.

Estimation of Energy Savings

To quantify energy savings for improved O&M practices you must determine the “inefficiency” of the present equipment. This is difficult. The following examples can be used to estimate the relative magnitude of savings that might be achievable:

- **Notched V-belts** can improve supply fan drive efficiency by 2 - 10 percent.

- A **dirty condenser coil** can result in 30 percent higher compressor energy. (See Reference #6 for calculation methodology).

- **Comprehensive tune-ups** have produced some positive results:

A project that tackled 25 commercial rooftop units in New England brought 11 percent average energy savings, with paybacks of slightly less than three years.

A similar project in Louisiana—"complete professional tune-ups" of 23 air conditioners in motels, restaurants, and grocery stores—brought efficiency improvements ranging from 22 to 42 percent. Paybacks were six months or less, largely because of the low cost of the tune-ups ($118 to $225 in 1992 dollars).

See Reference 5 for additional examples of savings potential.

Factors That Influence Operations and Maintenance Costs

The cost of O&M depends on several factors:

- **Age of the Equipment:** Older equipment costs more to maintain because it is out of warranty and needs more attention.

- **Service History of Equipment:** Equipment which has not been properly maintained for a long period may require extensive work. Service contractors might charge a premium.

- **Accessibility:** If it is difficult to gain access to the equipment, or to work around it, maintenance costs will be higher.

- **In-house or Contract Service:** The cost advantage of performing in-house service is greater for large facilities.

Factors that Impact Service Life of Package HVAC Equipment

Good maintenance practice will extend service life. The 1997 PG&E Retrofit Express Program assumed a 15-year life for packaged HVAC equipment, based on the equipment receiving adequate maintenance.

Laws, Codes, and Regulations

Indoor Air Quality

California Energy Efficiency Standards for Residential and Nonresidential Buildings include requirements for adequate ventilation to maintain acceptable air quality. Concern for air quality in the workplace may influence building owners and operators to set up O&M programs.

Ozone Depletion and CFCs

Because of the ozone-depleting effects of chlorofluorocarbons (CFCs), the U.S. Clean Air Act of 1990 calls for a reduction in CFC production. The Act applies to the servicing and disposal of packaged HVAC equipment in the following ways:

- Nearly all packaged units use R-22, a mildly ozone-depleting hydrochlorofluorocarbon (HCFC). Handling of this refrigerant is regulated by the EPA. As with other HCFCs, production of R-22 is slated to cease in 2010. Its use will be prohibited in new equipment beginning in 2020.

- The EPA requires fixing leaks only in cooling systems with a total refrigerant charge greater than 50 pounds. This excludes nearly all packaged equipment (a 20-ton unit has about 30 pounds of R-22).

- All refrigeration-system service must be performed by an EPA-certified technician.

- All refrigerant must be recovered from equipment removed from service, and these units must be labeled with a sticker before being recycled or placed in a landfill.

Definitions of Key Terms

- **Condenser coils** are heat exchangers that reject heat from hot, compressed refrigerant vapor. When cooled, the vapor condenses to liquid refrigerant.

- **Dampers** control the volume of air flow. In packaged equipment, they adjust the proportions of return air and outside air used for ventilation and “free cooling.” Some packaged equipment also includes exhaust dampers.

- **Economizers** include dampers and related controls to allow outside air to be used for cooling when its temperature is moderate. This is called “free cooling” because it reduces the work required by the mechanical cooling equipment. Economizers are often found on packaged equipment with airflows of 2,500 cubic feet per minute or more, and cooling capacities of 75,000 Btu/h or more.

- **Evaporator coils**, or cooling coils, contain liquid refrigerant. As warm air passes across the coil, it evaporates the refrigerant, which has a cooling effect on the air.

- **Ton** of cooling capacity is equivalent to a heat removal rate of 12,000 Btu/h.

References to More Information

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