PDHonline Course M132 (4 PDH)

The Performance Monitoring and Maintenance Audit of HVAC System

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Course Content

Each equipment for whatever purpose it is used is designed to perform a specific function under specific conditions. HVAC systems provide the building with an atmosphere conducive for higher productivity or pleasure. Therefore every attention must be given for its proper operation and maintenance.

It often becomes very difficult for a maintenance engineer to know *when* and *what* maintenance activity should be performed to keep the plant running. The maintenance activities should not be devoted only to increase the availability of the plant; the economic considerations also play a role; the plant should also run at designed efficiency levels. The best maintenance systems should result in

- High operating efficiency of plant
- High availability of plant
- Improved indoor quality and ambience
- Reduced energy consumption and cost savings
- Reduced unscheduled equipment repair and/or replacement
- Reduced capital costs for replacing equipment which fails prematurely
- Improved staff morale
- More capacity for less cost

Other than above factors, O & M activities are desired for:

Risks & Liability Issues

The Owners/Administrators need to understand the risk & liability issues associated with so called *"sick buildings".* One of the fastest growing sources of potential lawsuit is the concerns about indoor air quality. All efforts must be made to ensure "healthy buildings". EH&S should proactively advocate the importance of proper HVAC maintenance programs in accordance with the laid down criteria by OSHA, EPA standards and ASHARE.

OSHA - Operating Criteria

At a minimum the HVAC maintenance program must meet the annual requirements of OSHA §5142 (Mechanically Driven Heating, Ventilating and Air Conditioning (HVAC) Systems to Provide Minimum Building Ventilation). The guideline requires existing HVAC systems to be operated continuously during working hours (except for emergency or mechanical shutdowns) and that there be an inspection and maintenance program. Title 8 of CCR §5142 (OSHA) requires mechanical ventilation systems to be maintained and operated properly.

"The HVAC system shall be inspected at least annually, and problems found during these inspections shall be corrected within a reasonable time".

Inspections and maintenance of the HVAC system shall be documented in writing and the records shall be maintained for 5 years.

AHSRAE - Operating Criteria

As a goal each campus should meet ASHRAE guideline for the "Preparation of Operating and Maintenance Documentation for Building Systems "guideline 4-1993. These guidelines recommend O&M documentation that should include Operating Manuals, Factory Test Reports, and Construction Test Results for each piece of building equipment (i.e. supply fan, exhaust fan, boiler, chiller, cooling tower, heat exchange....). This equipment documentation allows the building owners to determine the maintenance schedule and the proper operating range for each piece of building equipment.

Safety First

Before any kind of maintenance is undertaken, consider three important safety precautions.

1. Disconnect all electrical power to the unit before removing access panels to perform maintenance. Please note that there may be more than one power connection switch.
2. Take special care to avoid sharp edges and rotating elements of the equipment, it's best to be very careful when you handle parts and work with your tools.
3. Take precautions against fall and hot surfaces. It is best to be equipped and careful when you reach units.

PART I Monitoring and Analyzing Performance

Tracking Performance

The important aspect of performance monitoring is to track actual performance of major equipment against expected performance. When O&M staff does not have adequate or correct information to assess day-to-day equipment performance, energy saving opportunities may be lost.

Establishing benchmark performance criteria and comparing the criteria to actual performance allows O&M staff to identify when equipment is not operating as efficiently as possible and to take corrective action.

The important O & M yardsticks for the management purview include:

- Energy conservation achieved
- Capacity & availability factors
- Forced and scheduled outages
- Days without injury/loss of work… Safety record
- Air & water issues… Environment record
- Spares, stocks and inventory control

The performance monitoring starts with collection of data on day-to-day basis. The data needs to be recorded on proper log sheets that provide an effective way of compiling data on plant performance. But these are of real use only if

1. The data recorded is accurate
2. The information is intelligently analyzed
3. Any problems identified are followed up

The formats of the log sheets may be different from plant to plant depending upon the complexity, but ideally a log sheet must contain the information on the normal operating range of various parameters so that out of limits readings can be readily seen.

Start with the chillers/compressors, as this is the most critical piece of equipment. These items consume the maximum energy and provide scope for energy conservation. Consider for example a sample plant room (figure below) with local instrumentation.

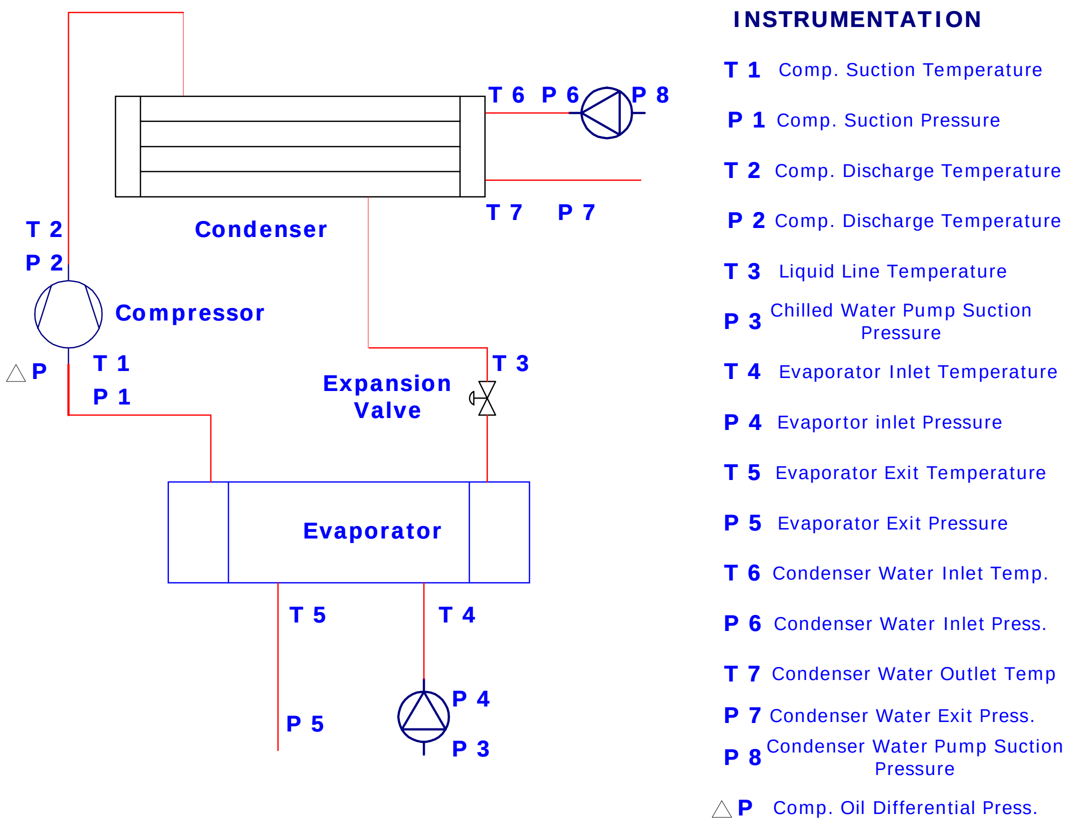

FIGURE - REFRIGERATION PLANT TYPICAL INSTRUMENTATION

A specimen log sheet should record all the instrumentation parameters. This shall permit to perform a full heat balance and then compare the actual plant performance with design performance. An analysis below shall demonstrate this. The saturation temperatures are recorded directly from the suction and discharge pressure gauges at the compressor.

		COMPRESSOR								
Date	Time	Hours Run	Amps	Suction Temp.		Discharge Temp.		Liquid Line Temp. T_3	Comp. Loading %	Oil Diff. Pressure
				Saturated P_1	Actual T_1	Saturated P_2	Actual T_2			
Recommended Value				1° to 5°	$P_1 + 3°$ to $P_1 + 7°$	$T_6 + 5°$ to $T_6 + 15°$		$P_2 - 2°$ to $P_2 - 5°$		> 3 bar
7/6/02	14.00	1546	96.3	2.8	6.4	36.6	58.0	27.5	100	4.6

*Data in meteric units

		CONDENSER					EVAPORATOR				
Date	Time	Water Inlet		Water Exit		Pump Inlet Pres.	Water Inlet		Water Exit		Pump Inlet Pres.
		Pressure P_6	Temp. T_6	Pressure P_7	Temp. T_7	P_8	Pressure P_4	Temp. T_4	Pressure P_5	Temp. T_5	P_3
Recommended Value		2.8 bar	30 - 32°	2.3 bar	36-38°	0.8 bar	2.5 bar	7 to 10°	2.0 bar	5°	0.6 bar
7/6/02	*14.00*	*2.76*	*28.0*	*2.3*	*33.4*	*0.8*	*2.5*	*7.2*	*1.94*	*4.8*	*0.6*

*Data in meteric units

Analyzing System Performance

The operating parameters indicate us the condition of equipments. The following questions may be asked.

- *Look at the operating load of the chiller/compressors.*

  What is its operating load? Is it 100%/ 50% / 25%?

  Is it operating at peak efficiency or at low efficiency range? Check the log sheet on the frequency.

  What can be done to operate the chillers at higher efficiencies? Revise the operating schedule of various sizes/models or number running?

- *Check the compressor discharge temperature?*

  Is this normal? Compare it with the recommended values derived from the operation manuals. The log sheet must record this value.

  Check the suction superheat?

  Is this normal? Check with the operation manual the correct value. The log sheet must record this value.

- *Check the log sheets for evaporative temperature and condensing temperature*

  Are these normal values? Compare with the previous log sheets and observe any deterioration with time.

  Compare the evaporator temperature with chilled water temperature. What are the differentials? Is this normal? Check with supplier's manuals for the correct value.

  Can the evaporator temperature be raised? What has to be done to raise it?

  Compare the condensing temperature with the cooling water temperature. What are the differentials? Is this normal? Check with manuals the correct values.

  Can the condensing temperature be lowered? What is the cause of high condensing temperature? Is it because of dirty coils or high cooling water temperature? When was the condenser cleaned last time? Is there air in the system or is it because of low cooling water flow? Or may be due to clogged strainer?

  What has to be done to lower it?

- *Check the temperature differential between the inlet and outlet of both the chilled water and cooling water*

  Are these values normal? Check any deterioration with time in the log sheets. Are the heat exchanger surfaces fouled with scale or corrosion? Is it time to perform de-scaling? Is the cooling tower operating satisfactorily? Is the cooling tower set at incorrect fan pitch or speed? Is cooling tower fill surfaces clogged? How does the leaving temperature compare with the ambient dry bulb and wet bulb temperature?

Technical Analysis

The system performance can be analyzed item-by-item. Analyze the data from the log sheets by comparing it with supplier's recommended figures. The out of range values could readily been identified and computed to evaluate the performance indices and the energy losses.

1. Evaporator:

The evaporator duty can be calculated by:

Duty = Water flow x Heat capacity x ($T_4 - T_5$) in °C

The water flow rating could be taken from the pump nameplate. Ensure that the discharge valves are fully open.

Say for 25 Kg/s pump capacity; remaining data as logged in the datasheet

Duty = 25 Kg/s x 4.18 kJ/Kg°C x (7.2 – 4.8)

= 250.8 kW

In FPS, use the empirical relation:

Duty = 500 x Flow in GPM x ($T_4 - T_5$) in °F

= 500 x 395 x (44.96 – 40.64)

= 853200 Btuh or 71.1TR

(Note: TR is acronym for tons of refrigeration. 1 TR= 12000 Btuh)

The heat transfer effectiveness of the evaporator is given by the formula:

Effectiveness = ($T_4 - T_5$) / ($T_4 - P_1$)

Effectiveness = (7.2 – 4.8) / (7.2 – 2.8)

= 0.545

This effectiveness can than be compared with the actual system design or commissioning data.

2. Compressor

The cooling duty and power requirements of a compressor depend primarily on the evaporating and condensing temperatures. Compressor performance is usually presented by manufacturers as either graphs or tables of duty and power for range of evaporating and condensing temperatures. This data is usually valid for full load operation and the necessary correction factors are applied for part load operation.

The actual power taken by the compressor can be calculated from the current taken. In our example say the current drawn is 106 amps

Assuming the three phase low voltage supply:

Power = 1.73 x Volts x Amps x Power factor

In our example

Power = 1.73 x 400 x 106 x 0.9

= 66 kW

The power factor of the motor can be checked through portable clamp meter or could be derived from motor nameplate. This shall be true if the motor is optimally loaded; with lower load the power factor is poor. The efficiency is the combined mechanical efficiency of the motor and of the drive system between motor and compressor. If there is a direct drive this can be taken as 100% and 95% for V belts.

3. Condenser

The condenser duty can be analyzed in a similar way to the evaporator. In refrigeration system the condenser heat rejection is more than the heat absorbed in the evaporator due to the fact that the heat of compression is also added to the system. Typically the heat of compression is to the tune of 22 to 28%. That's why the condensers are always bigger than the evaporators or have larger heat exchange surfaces.

Say for 100 TR refrigeration plant having a reciprocating compressor imparting 25% heat of compression at designed conditions, the condenser shall be designed for 125 TR duty.

The effectiveness of condenser is given by:

Effectiveness = $(T_7 – T_6) / (P_2 – T_6)$

= (33.4 – 28.0) / (36.6 – 28.0)

= 0.627

For air-cooled and evaporative condensers it is usual to use manufacturers published performance data. This gives the design heat rejection capacity for the measured condensing temperature and ambient air inlet temperature (dry bulb for air cooled condensers, wet bulb for evaporative condensers). For air-cooled condensers, this data is often expressed as a single figure for kW heat rejected per degree centigrade difference between condensing and air inlet temperatures.

Where air-cooled and evaporative condenser systems have a head pressure control system it is usually not possible to quantify condenser performance if the system is in operation.

Automatic Monitoring & Diagnosis

Today's building systems and controls are more sophisticated and complex than in the past. The building management systems (BMS) provide features of auto monitoring, data logging and an opportunity for energy-efficient O&M activities. These advanced systems allow a convenient way of remotely displaying and recording plant parameters. The calculations described above can be written into a fairly simple computer program that provides analysis in fraction of time.

Fault Finding and Remedies

The monitoring and analysis described above provides useful indication of where the problems are. Unfortunately, some refrigeration system faults give a number of symptoms and several faults give the same symptoms.

The table below lists the most common faults found on the reciprocating HVAC refrigeration systems. The table also lists the symptoms although it must be remembered that the fault might not show all the symptoms listed. It will quite often be the case that the symptom develops to such an extent that system cutouts may come into action before the fault is detected.

A word of caution; systems, which have been tripped, should not run unattended until the reason for the trip has been identified and rectified.

Also indicated in the table is the operational cost penalty of running the plant with the indicated fault. The figures quoted for loss of duty and decrease in “coefficient of performance” (COP) are typical of those found in actual installations, the actual values could be better or worse than these-eventually the system could be stopped by one of the safety cut-outs.

Common Faults and Solutions

Major Symptom	Other Symptoms	Fault	Solution	Operational Cost Penalty
Low Cooling duty compared with compressor curves	Bubbles in liquid line and low or zero sub cooling from condenser	System undercharged	Add refrigerant to correct level	Up to 25% or more reduction in duty and COP
	On HP float systems	HP float valve struck open, bypassed, gas passing	Determine why bypass valve was opened initially. Correct fault and close bypass valve	Up to 50% reduction in duty and COP
	High actual compressor discharge temperature and low compressor absorbed power	Broken or obstructed reciprocating compressor suction valve	Repair valve and identify and rectify cause of blockage or obstruction	Loss of duty in proportion to cylinders affected
	High actual compressor discharge temperature	Broken or obstructed reciprocating compressor discharge valve	Repair valve and identify and rectify cause of blockage or obstruction	Loss of duty in proportion to cylinders affected
Poor Evaporator Effectiveness	Low evaporating pressure, high water/air side pressure drop	Fouling of air/water side of evaporator	Clean evaporator and locate & cure source of fouling	Up to 15% loss in COP, 25% loss of cooling duty
	Low evaporating pressure, high apparent superheat	Blocked suction strainer	Clean suction strainer. Identify and rectify source of blockage	Up to 15% loss in COP, 25% loss in cooling duty

Major Symptom	Other Symptoms	Fault	Solution	Operational Cost Penalty
	Loss of oil from compressor crankcase	Oil accumulation in flooded evaporator Poor oil return from expansion valve system	Remove excess oil, install effective oil drain or re-circulation system	Up to 30% reduction in COP
	Possible high liquid line sub cooling, high suction superheat	Obstruction in liquid line	Locate and clear obstruction. Identify cause and rectify	Up to 25% reduction in COP
Poor Condenser Effectiveness	High condensing temperature, high liquid sub cooling	Very high overcharge of LP float or TEV system	Remove excess charge	Up to 10% loss of duty and 15% reduction in COP
	High condensing temperature, high liquid sub cooling	Air or non-condensing gas in system	Purge non-condensable gas from condenser	Up to 10% loss in COP
	High water/air side pressure drop	Fouling of air/water side of condenser	Clean condenser and locate & cure source of fouling	Up to 25% loss in COP, 10% loss in duty
Low Suction Superheat	Possible low compressor discharge temperature	Incorrect or faulty expansion device control	Identify and rectify fault	Up to 15% reduction in duty. Potential compressor failure due to liquid carry over
High Suction Superheat	Low liquid level in evaporator	System undercharged	Add refrigerant to correct level	Up to 10% loss of duty, 7.5% reduction in COP
Low Oil Differential Pressure	Foaming of oil in crankcase particularly on start-up	Refrigerant dissolved in crankcase oil due to crankcase heater failure or liquid refrigerant in suction gas	Check operation of crankcase heater. Oil temperature should be 50-60°C. If heater is OK check expansion device	Potential compressor failure

Acronyms:

1) COP stands for 'Coefficient of Performance' and is defined as the ratio of energy removed at the evaporator to energy supplied to compressor.
2) TEV stands for "Thermostatic Expansion Valve" and is provided at the inlet to the evaporator.

PART II Maintenance Considerations

Before regular maintenance program is undertaken, one must consider the building's functional requirements. The maintenance activities should not interfere with the mandatory functional requirements as far as possible.

1. *Operating Standards and Guidelines*

The airborne concentration of pollutants may never exceed the OSHA permissible exposure limits as defined in title 8 CCR, §5155.The mechanical HVAC system should be operated to meet the recommendations of ASHRAE 62-1989 "Ventilation for Acceptable Indoor Air Quality".

2. *Temperatures and Humidity*

For occupant comfort the temperature of occupied space should meet ASHRAE 55-1992 "Thermal Environmental Conditions for Human Occupancy" recommendation for acceptable temperature range.

ASHRAE 55 recommends an acceptable range of 68-75°F in the winter and 73-79°F in the summer. Most individuals consider a temperature range of 70°F - 75°F as comfortable.

The relative humidity of occupied space should be maintained below 60% to prevent condensation and microbial growth; but above 30% for comfort. The air velocity at the effected occupant should be 30 - 50 linear feet per minute (lfpm), air velocities over 50 lfpm may result in complaints of draftiness.

3. *Duration of Operation*

For energy conservation, building ventilation may be turned off when the building is not occupied, however the ventilation should be turned on to suitably pre-heat and ventilate the building prior to general occupancy. The building should have at least three air changes prior to general occupancy (typically at least one hour).

Operate equipment only when needed. Because occupant needs and schedules are constantly changing, operating schedules and strategies need to be continually adjusted. Equipment may be operating very efficiently, but when it's "on" and nobody's home, the only thing happening is energy waste.

Buildings using hazardous materials or with ventilation designed to operate constantly, may not have the ventilation turned off for energy conservation.

4. *Building Operating Pressure*

The building ventilation pressure should be slightly positive to the outdoors (0.1-0.3 inches of water) so that outdoor air is not drawn into the building except through the HVAC system.

Restrooms and other odor locations should be kept under negative pressure relative to "clean" locations.

Maintenance Strategies

Operations and Maintenance (O&M) has traditionally been defined as the processes related to the performance of routine, preventative, predictive, scheduled, unscheduled and emergency maintenance. It includes operational factors such as scheduling, procedures, and work/systems control.

More appropriately, operations and maintenance (O&M) is the coordinated integration of the operations, maintenance, engineering support, training, and administrative areas of any process in order to increase the efficiency, reliability, and safety of the process.

The maintenance could broadly be classified into two types:

1. "Breakdown maintenance"
2. "Preventive maintenance."

Breakdown maintenance is classified as maintenance that is done only when something breaks (or stops heating or cooling). By utilizing this method, it will directly and indirectly be the cause of low efficiency, excessive emergency repairs, downtime (especially in a production environment), and shortened equipment life. All of these results are not very cost-effective, and must be considered in figuring the cost of ownership within a building.

Yes, you may have lower upfront maintenance costs directly associated with the HVAC, but you must take into account that is not your "true" cost of operation.

The other method 'preventive maintenance' is truly the most cost-effective way to maintain a building or facility. The focus is on thorough periodic coil cleaning, proper refrigerant charges, prompt leak repairs, high quality filters, replacement of worn belts and pulleys, worn bearing detection and replacement, pneumatic system inspections, etc. Whether it is an in-house maintenance staff or an outsourced service provider, it is imperative that the equipment be maintained to limit the breakdowns, and in return you will receive lower energy expenses, less down time, longer life expectancy of the equipment, increased tenant comfort, and a more calculable operating cost in the long run.

"Breakdown maintenance may in the short term seem much the cheaper option but preventive maintenance means that the equipment is operating at its highest energy efficiency at all times and that down times are reduced."

Preventive Maintenance

The preventive maintenance (PM) program consists of various maintenance activities, which are carried out to detect the faults or avoid the faults before it leads to a break down. It is also a method of budgeting and controlling maintenance expense. It pinpoints problem areas. It helps avoid repetitive maintenance, excessive parts replacement, and purchasing errors. Thus money spent on a well-planned system of PM reduces profit loss due to breakdown, emergency work and related parts failure.

In order to introduce controls, the PM program must be effective but very simple to avoid assigning administrative chores to maintenance for record keeping etc.

Preventive Maintenance Survey & Schedule

The survey is essential to establish a list of all equipments on the property that require periodic maintenance. The survey and schedule list should cover all items of equipment according to physical location. The log sheet should list the following columns:

1. Items
2. Location of item

3. Frequency of maintenance
4. Estimated time required for maintenance
5. Time of day maintenance should be done
6. Brief description of maintenance to be done
7. Maintenance resources (personnel/machines) assigned to do the work

Use of Preventive maintenance schedule

At some time before the beginning of the week, the supervisor of maintenance will take a copy of the schedule. He will go over the assignments in person with each maintenance technician/engineer.

After the maintenance personnel have completed their work, the supervisor shall note this on the schedule by planning a check under the completed for that day and index card system for cross checking the PM program.

The supervisor or his subordinates will check the schedule daily to determine that all work is being done according to the plan. At the end of week it will be ensured that work has been completed. It will then be filed.

Any repair or replacement of parts on a particular piece of equipment should be noted on the preventive maintenance schedule. The work done should be written in the weekly schedule section or reference should be made to an attached sheet if more space is necessary. This will provide a history of repairs or replacements on each piece of equipment.

The supervisor of maintenance or mechanic should analyze these schedules quarterly to determine if certain pieces of equipment are requiring more than acceptable maintenance and if replacement of the piece of equipment if necessary.

Data from the preventive maintenance cards and repair records should be compiled and analyzed to pinpoint high cost areas, and labor etc, plus the necessary information for yearly budgeting and other purposes.

Preventive Maintenance Activities

In general activities should be divided into daily, monthly, half yearly and yearly periods.

Daily maintenance activities are those that have to do with the checking of water levels, water conditions, heating up of parts, hand oiling and whatever may be termed a daily once over.

Monthly activities are usually those specified by the manufacturers as routine checks on oil levels in reservoirs, check for leaks of the refrigerant, oil and water cleaning of electrical apparatus, filters spray nozzles and checking of control devices, bell tension scale traps and purging.

Yearly activities require the opening up of condensers for examination, dismantling go of machines and any apparatus to be shut down for prolonged periods.

The various maintenance activity schedules for a central plant HVAC system is as follows:

Daily Activities

- Check motor and starter for over heating
- Check bearing for overheating
- Check water level and ensure flow of make up condenser and chiller water system
- Check condition in air-conditioning area at least twice in a day
- Ensure that the plunger of no volt coil of all starters particularly of compressor motor falls promptly when de-energized.

Weekly Activities

- Test for refrigerant leak with halide torch
- Check water distribution
- Check float valve operation in all water tanks and expansion tank
- Check and clean filters
- Check belt tension and alignment
- Check pump glands
- Check solenoid valves for proper operation and closing

- Clean water strainers
- Check and clean all drains and over flow points
- Drain flush and clean water tanks and troughs
- In case of oil lubricated bearings of fans, motors, gears etc, check all level and dirt in oil wells
- Cooling tower water systems should be treated to control the growth of microbial contaminants.
- Dose cooling tower basin with biocides and/or use of physical methods to kill microorganisms plus routine cleaning and disinfect ion. Routine treatment with a biocide known to be effective against Legionella, coupled with good cleaning practices, should be effective in controlling the amplification of Legionella

Monthly activities

- Check setting and test operation of all safety controls and operating devices
- Check and clean contact points in starters
- Check efficiency of heat transfer equipment by comparing temperature, pressure and leaving temperature differential including water cooled heads in compressors, where used and plan cleaning where necessary
- Clean spray nozzles
- Periodically check and calibrate the temperature, pressure, and air velocity sensors per manufacturer recommendations.
- Volume control and back draft dampers must be cleaned and checked for free operation. Lubricate bearings if required.

Half Yearly

- De-scale and clean water tubes in condenser and if necessary in chillers
- Remove grease from all bearing, clean and repack
- Check all strainers repair /replace where necessary
- Clean/wash air filters
- Charge pump gland packing
- Clean cooling coil fins (more often if dirty)
- Clean standpipe and spray headers in air washers/ cooling tower

- Change compressor oil after cleaning
- Inspect, clean with wiping cloth, and lubricate all dampers
- Clean or change the air filters when the pressure drop across the filter reaches the near maximum or on a regular schedule, based on visual inspections and pressure measurements.
- Filters should be changed if they become wet or if microbial growth on the filter media is visible, or if they collapse or become damaged to the extent that air bypasses the media.

Yearly

- **Air Balancing**

  Proper testing and balancing should be conducted to ensure that HVAC systems meet design, comfort and health requirements, as well as, save on energy consumption. The building should be balanced by a professional to design specifications as called out in the mechanical systems "As-Built" drawings. Airflow rates should be measured in accordance with ANSI/ASHRAE Standard 111-1988 or other approved procedure. If airflow rates are found to differ from current design airflow rates by more than 10%, these findings should be brought to the attention of responsible party. No ventilation changes should be made without the proper test equipment to measure changes.

  Ventilation balance reports should contain all of the final balanced readings. The balance report should be updated if any changes are made. These reports serve as a valuable reference to help trouble shoot problems should they develop.

- **Plenums/Ducts**

  Supply and return air plenum systems (in representative locations) should be inspected for cleanliness, obstructions that block the air paths, water damage, visible microbial growth, or hazardous materials. Corrective action should be taken to correct any unsatisfactory situations.

Overhaul

- Check and tighten hold down bolts and anchorages
- Check dampers and damper operators for freeness in operation, clean and lubricate
- Check for obstructions, loose boards, and fallen insulation on air ducts and return air passages

- Drain oil from compressor, clean oil filter and crankcase and replace oil (this may be done once in six months if oil appears dirty)
- Check all wirings for loose contacts and rectify
- Drain oil from gearboxes, clean oil sump and replace oil

Mechanical Maintenance

The normal wear & tear of rotating equipment and the deterioration of heat exchange surfaces with time require extra precautions and major check against failure. Unlike the routine operating inspections (described above) are done during the cooling season whose primary objective is to enhance performance and energy savings, the major inspection (mechanical maintenance) is needed at least during the first seasonal start each year. This is essential for reliable operation and minimizing down time. The frequency of multiple inspections can be determined by reviewing manufacturer recommendations, equipment operating hours, and inspection results.

The identification and monitoring of critical equipment is very important. Based on the trend of utility one can predict the behavior of the running plant and accordingly schedule the maintenance activities. The maintenance plan must identify risks associated with the equipment failure, need for standby equipment/spares, minimum time for replacement/rectification, skilled in-house personnel or outside agency to do the job etc. etc.

Air-conditioning and refrigeration plant consist of various critical equipments like motors, compressor/s, cooling tower, condenser, evaporator, pumps, AHU accessories and auxiliary units. To identify various parameters it is easy to proceed in the following four steps:

1. Identification of major equipment
2. Major problems or failures that can occur
3. Probable causes for problem/malfunction/failure
4. Identification of parameters that can indicate problem

Compressor & Motor: There can be number of problems in motor compressor unit. However some of the most commonly found problems are as follows.

MAJOR PROBLEM	PROBLEM CAUSES	PARAMETER EFFECTED
Bearing Failure	Lubrication, wrong fitting, normal wear & tear, misalignment, unbalance	Temperature, noise, shock pulses, motor current, vibrations
Coupling Misaligned	Loose bolts, uneven foundation, wrong installation	Vibrations
Unbalance in Pulleys	Wrong fitting, worn out belts	Vibrations, Fluctuating motor current
Low Compressor efficiency	Broken or struck valves, worn rings, carbon deposits	Suction pressure/ temperature, discharge pressure/temperature, quantity of refrigerant flowing

It is generally typical to have a standby chiller for operation emergencies that ensures reliability. But it is very important to schedule the operation in such a way that both duty and the standby equipment runs for almost same hours. The essential spares must be available handy. It is important that the chillers are optimum ally loaded to ensure energy efficiency. The number of small chillers provides such flexibility.

Pumps & Motors: Pumps & motors are having most of the problems as listed under compressor/motor. Additional problems may be low discharge of the pump. Reasons may be ‘cavitations’, faulty impeller, gland leakage, which can be traced by monitoring the parameters head developed, discharge, vibrations shock pulses etc.

AHU Blowers & Package Equipment: Here also the problems are somewhat similar. Some additional problems may arise due to blower imbalance, misalignment of pulleys, worn out belts, choking of filters, loose joints etc.

Generally it is not typical to have a standby AHU but one can plan to have a spare fan motor for multiple AHU's considering one failure at a time. The same is true for cooling tower fan motor.

Evaporators and Condensers: The main issues of concern that affect the efficiency of condenser/evaporator and their overall heat transfer are as follows:

MAJOR PROBLEM	PROBLEM CAUSES	PARAMETER EFFECTED
Condenser/Evaporator low heat transfer efficiency	Surface deposits, scaling, rust, oil film, bad insulation	Inlet/outlet temperatures, fluid flow, pumping power
Leakage	Rusting, Loose joints	Flow of refrigerant, suction temperature

Specific Actions for Chiller Maintenance

(The information is an extract from the maintenance manual of Carrier screw compressors)

Here are some of the specific actions that are part of a comprehensive screw chiller maintenance plan.

Vibration analysis: By monitoring the vibrations omitted by any equipment we can very easily find the faults like unbalance, misalignment, bearing condition, condition of impellers, loose belts, gear teeth problems etc. Vibration meters and vibration analyzers could be used for monitoring. To ensure accurate readings, take successive measurements at the same location and operating conditions. Contact the equipment manufacturer for the acceptable vibration displacement and peak velocity values.

Rotors and Motors: The screw compressor type, open or hermetic, determines the necessary frequency of vibration checks. Open-drive compressors require frequent vibration measurements to check proper alignment between the motor and compressor. Take vibration readings on the motor and compressor, and make adjustments accordingly. With hermetic compressors, vibration measurements should be taken every five years.

Both hermetic and open-drive motor windings need to be checked annually for insulation integrity using a megohm meter.

Oil lubrication & filtration: The key to good maintenance of rotating elements is proper lubrication. Make sure the proper type and grade of oil is maintained at the recommended level, temperature, and pressure. Change the oil after the first year of operation and at least every three years after that. Change oil filters and oil reclaim system strainers (if present) once a year, or sooner.

Condenser: Water-cooled condensers usually have an open-type water circuit and the tubes may be subject to contamination and scale. Clean the condenser tubes with a rotary tube cleaning system at least once a year; more often if the water is contaminated. Don't use wire brushes to clean the tubes. To avoid scratching the tube walls, use brushes designed for that purpose.

For water-cooled condensers, inspect the entering and leaving condenser water sensors for signs of corrosion or scale. Replace sensors if they're corroded, or remove any scale. Higher than normal condenser pressures, together with an inability to reach full refrigeration load, usually means dirty tubes or air in the machine. If the operating log indicates a rise above normal condenser pressure, check the condenser refrigerant temperature against the leaving condenser water temperature. If the reading is more than what the design difference should be, the condenser tubes may be dirty or water flow incorrect.

Water treatment Untreated or improperly treated water may cause corrosion, scaling, erosion, or algae. You or your customer may have to call on the services of a qualified water treatment specialist to develop and monitor a treatment program.

Eddy current testing: Perform an eddy current tube test every five years, depending on water treatment. Eddy current testing is the process of inducing small electrical currents into a heat exchanger tube and observing the interaction between the tube and the current. The testing will detect tube degradation such as pits, cracks, or wall loss.

Air-cooled condenser: If the condenser is air-cooled, straightens the fins and powers wash the coils. Check the fan motors, pulleys and belts, and lubricate the bearings as needed. Clean the fan blades, if necessary, and tighten all electrical connections. Explain to owners of units installed in corrosive environments that coil cleaning should be scheduled regularly.

Evaporator: Inspect and clean evaporator tubes at the end of the first operating season. Since evaporators are typically a closed system, the inspection results will determine the scheduled frequency for cleaning and whether water treatment is adequate in the chilled water/brine circuit. Follow the same procedure for condenser tube cleaning and sensor inspection.

Refrigerant filters Change the refrigerant filter/drier once a year, or sooner if filter condition shows you need to. A moisture indicator will alert you to the presence of moisture in the refrigerant. If moisture is present, locate its sources immediately by doing a thorough leak check. Whenever the indicator shows there's moisture in the system, replace the filter drier.

Relief valves: Relief valves protect the system against potentially dangerous effects of over pressure. To ensure against damage to the equipment and possible injury to personnel, these devices must be kept in peak operating condition. At least once a year, disconnect the vent piping at the valve outlet and carefully inspect the valve body and mechanism for any evidence of internal corrosion, rust, dirt, scale, leakage, etc. If you find corrosion or foreign material, don't attempt to repair or recondition it, always replace the valve. If chillers are installed in corrosive atmospheres, or their relief valves are vented into a corrosive atmosphere, make valve inspections at more frequent intervals.

Leak testing: Leak test the entire chiller annually. Before repairing any leaks, transfer the entire refrigerant from the leaking vessel. If the chiller has been opened for service, pressurize and leak test the machine or the affected vessels.

Controls: Control maintenance is generally limited to cleaning and tightening connections. Vacuum all cabinets to eliminate dust and debris build-up from components. With microprocessor-based controls, verify that the most recent control software is installed. Check the service history for abnormal values or alarms and make adjustments as necessary. If condenser water control is used, verify that the pneumatic or electronic controls are operating correctly to ensure bypass when needed. Annually check all pressure transducers against a good pressure gage.

Routine Maintenance Considerations

Regular maintenance is needed to keep equipment clean and functioning properly and to avoid wasting energy. The following checklist should be part of the maintenance program:

1. Make sure all filters are clean and in place. Use efficient filters. This is the first line of defense in keeping HVAC systems clean and efficient.
2. Check controls for proper operation. The maintenance of controls includes periodic calibration and regular cleaning of contacts; keeping it free from pitting/carbonization.
3. Check instrument bellows/contacts for satisfactory operation
4. Check if expansion/contraction of bellows/diaphragm OK
5. Linkages should operate smoothly throughout their full range.
6. Check air balancing for proper distribution. Dampers and valves should provide proper flows.

7. Check time clocks and programmed schedules to see if equipment run-time can be reduced. If the facility has an energy management system, use its data tracking (trending) capability to determine whether components actually operate, as they should.
8. Check heating and cooling coils for dirt, clean as required. Clean all heat transfer surfaces clean (coils, heat exchangers).
9. For indoor evaporators, keep the outside air intake free of debris. Clean the filters regularly. After years of service the exchanger surface will become crusted with grease and dirt that collects during condensation. Removing this accumulation will probably take solvents or degreasers probably once a year.
10. The condenser coil being open to atmosphere is prone to dust. The cleaner it is kept, the better it transfers heat. Rinsing with a garden hose occasionally when the unit is not running will help keep it operating efficiently.
11. The condenser fan moves air across the coil to increase the transfer of heat. It is critical to the system. Obstructing the flow of air will not only reduce efficiency but can lead to compressor failure. Keep debris and objects away from the coil and fan to allow maximum airflow. Some condenser fan motors have sealed bearings; others need lubrication.
12. Check drives efficiency. Align and adjust belts; check motor power factor & efficiency
13. Service chillers, cooling towers, and boilers according to manufacturers' procedures
14. Be sure to capitalize on the free cooling provided by spring if your facility allows it. Set cooling equipment control parameters to run at maximum efficiency
15. Check all cool surfaces (refrigeration & chilled water lines and ducts) for proper insulation, paying particular attention to exposed surfaces where insulation is vulnerable to deterioration from the sun.
16. Check and clean cooling towers and air-cooled condensers from sludge.
17. Make sure all belts are in good shape and not slipping. A slipping belt can cut system efficiency by 10 to 50 percent.
18. Make sure all system motors are properly lubricated.
19. For gas furnaces, routine maintenance includes: monthly filter replacement or washing the electronic air cleaner grids when in constant use, and cleaning the humidifier if so equipped. A properly functioning gas burner will not need cleaning. Black soot is evidence of an incorrect air mixture or other malfunction. A qualified serviceman should check this.

20. The mineral deposits from the water will reduce the effectiveness of the humidifier after consistent run. A 50% mixture of vinegar and water will usually dissolve or help clean away deposits.
21. Stagnant water sitting in the blocked drain pan, or humidifier during the off-season can be a breeding ground for bacteria. Turn the water off and clean the humidifier if possible when heating season has ended.
22. Check level of equipment to make sure moisture drains properly out of the unit. If you notice that water or ice collects beneath the unit, arrange for it to be drained away from the equipment.
23. Check your ducts for air leaks. First look for sections that should be joined but have separated and then look for obvious holes.
    If you use duct tape to repair and seal your ducts, look for tape with the Underwriters Laboratories (UL) logo to avoid tape that degrades, cracks, and loses its bond with age.
24. Be sure a well-sealed vapor barrier exists on the outside of the insulation on cooling ducts to prevent moisture buildup
25. Check cooling water quality and initiate proper chemical treatment program
26. Chiller Maintenance
    - ✓ Review and evaluate log readings
    - ✓ Test chiller for leaks
    - ✓ Drain oil, remove sample for analysis (as needed)
    - ✓ Change oil, filters, and strainers (as needed)
    - ✓ Transfer refrigerant or isolate charge, pull sample for analysis
    - ✓ Change and replace refrigerant filters
    - ✓ Perform a megohm resistance test on the compressor motor windings
    - ✓ Clean float chamber and valve assembly, check for proper operation and obstructions
    - ✓ Check transducers, and calibrate as required
27. Evaporator and Condenser
    - ✓ Drain water from condenser; remove heads, clean/brush condenser tubes, re-assemble condenser heads
    - ✓ Drain water from cooler; remove heads, clean/brush cooler tubes, re-assemble cooler heads (as required)

- ✓ Evacuate machine to dehydration; vacuum, perform a standing vacuum test

28. Supply, Return & Exhaust fans

    - ✓ Check fan operation for excessive noise, vibration belt tightness and temperature of supply air.
    - ✓ Bearings should be checked to be sure all setscrews and bolts are tight.
    - ✓ Check v-belts for wear, and belt tightness.
    - ✓ Check seismic snubbers and spring isolators to see if they are grounded out.
    - ✓ Check at 60 to 80% speed of the fans. Fan flex connections should not be strained. Clean condensate drain pans and drains. Clean outside air screens, dampers, damper motors and linkage. Lubricate as needed. Check, replace filters as prescribed by particular manufacturer, or when the total pressure drop through the prefilters and filters exceeds 1.5 inches water gauge.
    - ✓ Grease bearings as required with the proper grease.
    - ✓ Inspect operation of motor starters and wiring.
    - ✓ Check amperage and voltage to motors and compare with nameplate rating.
    - ✓ Grease motors as required.
    - ✓ Check v-belt alignment, proper belt tension, belt wear and dirt.
    - ✓ Check motor and fan sheaves for proper alignment, replace v-belts if worn.
    - ✓ Check and clean fans and scrolls.

Measuring the quality of your O & M Program

O & M Program Performance Indicators

- Corrective maintenance backlog
- Preventive maintenance items overdue
- Maintenance staff turnover rate
- Maintenance rework
- Surveillance versus demand failure discovery

- Number and duration of equipment out of service
- Mean time to return to service
- Backlog of engineering change notices

Operations & Maintenance Yardsticks

- Capacity factor
- Output/capacity
- Availability factor
- Forced and scheduled outages
- Heat rate
- Btu/kWh
- Safety record
- Days w/out injury/loss of work
- Environmental record
- Air/water issues
- Non-fuel O & M costs
- Equipment life issues
- Inventory control
- Stocks control, JIT
- Absentee rate
- Personnel turnover

Barriers to an "Operations & Maintenance" Philosophy

- Budget and regular costs
- Limited staff
- Lack of training
- Inadequate diagnostic equipment
- Missing technical documentation
- Inadequate building/equipment metering
- Lack of management commitment
- Poor morale

Course Summary

The foremost step of any service plan is to formulate a comprehensive schedule and proactive service plan to avoid breakdowns and to ensure reliability of air-conditioning and refrigeration system. Typically, the primary goal of preventive maintenance is reliability but it should be redefined to include activities critical to energy-efficient operation.

Keep an accurate log of all basic data such as compressor amps and volts, suction and discharge temperatures and pressures, oil pressures, etc. This provides a baseline for comparison with future data.

Inspections and corrective actions should be fully documented. Records on the HVAC system should be maintained for at least five years and should be readily available upon request.

Well-planned comprehensive maintenance will return dividends to the building owner in assuring comfort, indoor air quality, and reduced operating costs.