

**KATHMANDU UNIVERSITY**  
**SCHOOL OF ENGINEERING**  
**DEPARTMENT OF MECHANICAL ENGINEERING**

A Report on  
**Maintenance of**



**HVAC System**

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MEPP 408 Maintenance Engineering  
Assignment  
December 2023

## **Abstract**

The Maintenance Report on HVAC Systems is a detailed guide to Heating, Ventilation, and Air Conditioning (HVAC) systems. It explains the importance of air conditioning in different contexts and provides insights into general classifications, foundational concepts, and installation considerations. The report outlines the purpose, components, and working mechanisms of HVAC systems. It also discusses current practices and recommended procedures for HVAC maintenance, including objectives, methodologies, and routine considerations, supplemented by a detailed maintenance and inspection checklist. The report explores advanced condition monitoring techniques, including vibration analysis, temperature monitoring, and real-time systems, to ensure proactive system health. It also presents preventive techniques for corrosion in HVAC systems and discusses failure analysis, its causes, descriptions, and associated tools. The section on tools and equipment sheds light on instruments vital for precise inspection and monitoring. The report identifies safety hazards inherent in HVAC system maintenance and recommends corresponding precautions to ensure technician well-being. Finally, the report concludes with a summary, highlighting the holistic approach required for effective HVAC maintenance. This comprehensive guide is a valuable resource for HVAC professionals, encompassing safety, engineering principles, and cutting-edge maintenance practices.

*Keywords: HVAC, Corrosion, Failure Analysis, Inspection & Checklist*

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# 1. Introduction

## 1.1 HVAC (Heating, Ventilation, and Air Conditioning) System

The HVAC system stands for heating, ventilation, and air conditioning, is responsible for regulating temperature levels and moving air between indoor and outdoor areas in both residential and commercial buildings. It can filter the air and maintain optimal humidity levels for comfort, which helps keep occupants healthy by removing dirt particles from the air they breathe.

To maintain optimal conditions within a space, the HVAC system balances the supply or extraction of energy, depending on the season. During winter, it acts as a heating source, while in summer, it functions as a cooling source, managing both sensible and latent heat. An air conditioning system comprises two main components: the air conditioning plant and the thermal distribution system.

The HVAC system plays a significant role in enhancing the well-being and productivity of occupants by regulating temperature, humidity, and air quality to maintain optimal environmental conditions.



*Figure 1 Household AC System [1]*

To provide acceptable indoor air quality, the HVAC system takes in air, conditions it, and circulates it. The air is taken in through a vent or ductwork and filtered to remove dust, pollen, and other particles. Then, depending on the season and the temperature inside the building, it is either cooled or heated. Finally, a fan circulates the conditioned air throughout the space.

All these processes start with a thermostat that senses the air temperature in the space. If the thermostat is set to “cool,” the HVAC system will take in air from the area, lower its temperature, and blow the cooled air back into the room. Conversely, if the thermostat is set to “heat,” the HVAC system will take in cold air and blow warm air back into the space. The ultimate goal is to improve indoor air quality and keep occupants comfortable.

The air conditioning plant is responsible for transferring energy using air, water, or refrigerant as media. This plant serves two roles, supplying warmth during winter and extracting heat during summer. The thermal distribution system facilitates the circulation of these media between the



plant and the conditioned space. In addition to temperature control, it also ensures Indoor Air Quality (IAQ) by introducing the required amount of fresh air.

Air conditioning systems are divided into two categories: unitary and central systems [2]. Unitary systems, such as split air conditioners, are decentralized, with units placed around the periphery of the conditioned space. On the other hand, central systems involve a unit located farther away, achieving climate control through a network of air or water distribution systems, like chillers.



*Figure 2 Common Type of Air Conditioning System [3]*

Choosing an air conditioning system depends on various factors, including capacity, performance, spatial requirements, initial and operating costs, life cycle considerations, maintenance demands, reliability, flexibility, and architectural constraints. The selection process involves a thoughtful evaluation of these aspects to ensure that the chosen system aligns with specific needs and operational considerations.

### **1.2 Significance of Air Conditioning:**

Air conditioning systems are crucial in both residential and commercial settings as they create an environment that is comfortable and conducive to productivity. These systems efficiently regulate temperature and humidity levels, which is essential for maintaining a pleasant atmosphere and preserving perishable goods, electronic equipment, and the well-being of individuals.

### **1.3 Purpose of the Maintenance Report:**

The purpose of this maintenance report is to explain how air conditioning systems work and why it's essential to maintain them to keep them functioning at their best. The report covers the technical details of how the systems are built and operated, as well as the maintenance procedures required to keep them running smoothly. It's important to understand the significance of routine maintenance to ensure the longevity, efficiency, and reliability of air conditioning systems.



*Figure 3 Technician maintaining AC [4]*

In addition to providing an overview of the system's current state, this report includes a user-friendly maintenance checklist, Failure Modes and Effects Analysis (FMEA/FMECA), and Fault Tree Analysis (FTA) to make the complexities of the system more accessible to a broader audience. These tools help people understand the system's workings, maintenance schedule, and stages of operation in various settings, such as industrial and commercial spaces. The report also offers practical recommendations for optimizing system functionality, preventing breakdowns, and promoting cost-effective and sustainable management practices.

Overall, this report is a valuable guide for anyone with an interest in air conditioning systems. It explains the importance of maintenance in simple language and provides useful tools and recommendations to help keep systems operating at their best.

#### **1.4 Overview of Maintenance in Air Conditioning**

Air conditioning service and maintenance are essential for the efficient operation of HVAC systems. Trained engineers need to carry out the process as there are harmful gases involved. The service follows planned preventative maintenance (PPM) guidelines, which include various checks and inspections. Compliance with regulations, including F-Gas, is crucial, and regular service checks are necessary for different types of air conditioning systems. Neglecting the service can lead to downtime, discomfort, and compliance failure. Proper certification and training for service engineers ensure health and safety, and PPM provides benefits like improved reliability, compliance, and energy efficiency. Ignoring the service can lead to operational issues, discomfort, and legal consequences. The EU's F-Gas phase-down aims to reduce harmful refrigerants, and companies like Thermodial stress the importance of PPM for optimal efficiency and cost-effectiveness [5].

## 2. Maintenance Engineering

### 2.1 Introduction to Maintenance

Maintenance refers to the process of carrying out functional checks, servicing, repairing, or replacing necessary devices, equipment, machinery, building infrastructure, and supporting utilities in industrial, business, and residential installations. Maintenance engineering is a field of study that applies engineering concepts to optimize equipment, procedures, and budgets to achieve better maintainability, reliability, and availability of equipment.

The primary goal of maintenance is to retain or restore a piece of equipment, machine, or system to its specified operable condition to achieve its maximum useful life. This may involve repair or replacement activities, which should be carried out with the minimum possible cost to reach an acceptable productivity condition. Maintenance can be planned, which involves taking steps to avoid equipment failure, or unplanned, which involves bringing something back to working order after it has failed [6].

### 2.2 General Classification of Maintenance

Engineering maintenance can be classified as [6]:

#### 2.2.1 Classification 1:

- Reactive Maintenance (Unplanned Maintenance)  
This approach, also known as unplanned maintenance, is often driven by failures and breakdowns. It involves executing work without advance preparation, making it suitable only for urgent repairs and emergency maintenance. However, the goal is to ensure that emergency/breakdown maintenance constitutes less than 2% of the total workload.
- Proactive Maintenance (Planned Maintenance)  
Proactive maintenance is a strategy that focuses on continuous improvement. It involves planning and preparing work in advance and executing preventive maintenance on time. The goal is to eliminate problems before they occur, which allows for effective planning and reduces the need for corrective maintenance.

#### **Benefits of Planned (Proactive) Maintenance:**

- i. Elimination of unnecessary repairs
- ii. Reduction in rework costs
- iii. Decreased lost production due to failures and downtime
- iv. Lower repair parts inventory
- v. Increased process efficiency
- vi. Enhanced product quality
- vii. Extended operating life of plant systems
- viii. Augmented production capacity
- ix. Reduced overall maintenance costs
- x. Increased overall profit

### 2.2.2 Classification 2:

- Corrective Maintenance
- Preventive Maintenance
- Predictive Maintenance

### 2.2.3 Classification 3:

- Corrective Maintenance
- Preventive Maintenance
- Predictive Maintenance

Types of Maintenance:

- Corrective Maintenance:
  - Performed after a failure has occurred or is imminent.
  - Can be planned or unplanned.
  - Includes Remedial, Run to Failure, Emergency, and Deferred Maintenance.
- Preventive Maintenance:
  - Aims to prevent failures from occurring.
  - Involves maintenance before equipment failure.
  - Includes Time-Based (Routine/Scheduled), Usage-Based, Opportunistic Maintenance, and Fault/Failure Finding Maintenance.

Preventive maintenance is further classified into:

- Routine/Scheduled Maintenance:
  - a. Time Based Maintenance
  - b. Usage Based Maintenance
- Risk Based Maintenance
- Fault/Failure Finding Maintenance
- Opportunistic Maintenance
- Predictive Maintenance:
  - Maintenance based on predictions of failure.
  - Involves monitoring, predicting problems, and maintaining to increase reliability.
  - Includes Condition-Based Maintenance, Statistical-Based Maintenance, etc.

### **Corrective Maintenance:**

Corrective maintenance implies repairs made after the equipment has failed. It can be further divided into:

- Emergency/Immediate Corrective Maintenance (Run to Failure)
- Deferred Corrective Maintenance

- Remedial Corrective Maintenance

### **Emergency/Immediate Corrective Maintenance:**

- Oldest type of maintenance approach.
- Equipment allowed to run undisturbed until it fails, and repair is undertaken after failure.
- Suitable for small factories with few simple pieces of equipment.
- Not recommended for large industries with critical components.

### **Deferred Corrective Maintenance:**

- Corrective maintenance activities delayed to avoid affecting the production process.
- Commonly practiced for non-critical or redundant assets.
- Reasons include non-criticality, cost considerations, inaccessibility, and unavailability of spare parts.

### **Remedial Corrective Maintenance:**

- Involves activities performed to temporarily or permanently eliminate the source of failure without interrupting production.
- May include replacing items or transferring workload to redundancy.
- Requires accurate historical data, expertise, proper repair procedures, and adequate time for repair and verification.

## **2.3 Principles of Maintenance Engineering**

Principle of Maintenance are:

- i. Safe and effective operation: It is important to operate the equipment in a safe and effective manner to achieve the desired production targets on time, while making efficient use of resources.
- ii. Planning of maintenance function: All maintenance functions should be carefully planned to ensure the effective utilization of manpower and materials
- iii. Adherence to planned maintenance strategy: It is important to adhere to the maintenance strategy, including the use of manufacturer information on the life and maintenance schedules of the equipment
- iv. Manpower for maintenance: The manpower requirement should be evaluated based on the time and motion study, satisfying the need in case of overhauls, replacement, emergency and unscheduled repair.
- v. Training of maintenance workforce: Training should be an integral part of any good maintenance system, helping the workforce to learn about modern techniques, recent trends in maintenance, and to develop strategies to meet the growing demands of the industry.
- vi. Establishment of work order and recording system: A proper work order system should be established, indicating the nature of work, series of operations to be followed for a particular job, and a recording system to monitor them.

- vii. Prediction and control of spare parts: It is important to have a system in place to predict and control the supply of spare parts.

### 3. HVAC System

HVAC is an abbreviation for heating, ventilation, and air conditioning. These systems are essential setups that consist of three processes: heat addition, heat extraction, and conditioning. HVAC systems are found almost everywhere, including homes, industrial locations, food processing stations, organic warehouses, marine systems, etc. These systems are often used to control atmospheric conditions based on the needs of humans and industrial operations.

The heating, ventilation, and air conditioning (HVAC) system is a comprehensive setup that can heat or cool the air while conditioning the air quality per the requirements. The HVAC systems can be used for cooling, heating, moisture control, dust removal, and oxygen replenishment in indoor locations.

#### 3.1 Purpose of an HVAC System:

- Air Quality: Purifies indoor air by removing pollutants, dust, and bacteria.
- Temperature Control: Ensures a comfortable temperature year-round.
- Humidity Management: Maintains balanced humidity levels.
- Dust and Moisture Removal: Eliminates smoke, dust, and excess moisture.
- Oxygen Replenishment: Acts as an oxygen replenisher.

#### 3.2 HVAC Systems and Equipment

The common HVAC systems and equipment are as follows:

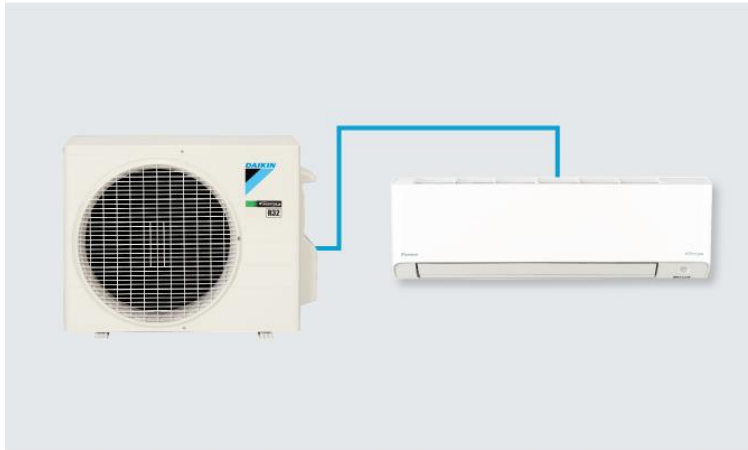
1. Window Air Conditioners (Window AC):



*Figure 4 Window Ac [7]*

- Decentralized Unitary System.
- Compact units fixed in windows, providing cooling for a single room.

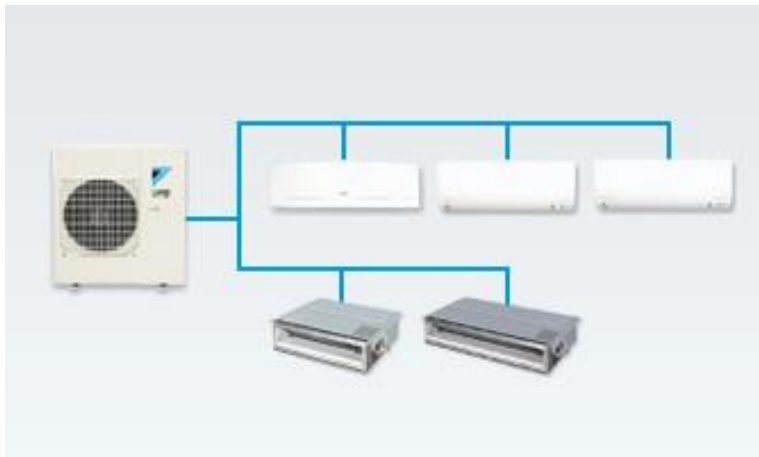
## 2. Split Air Conditioners (Split AC):



*Figure 5 Split AC [8]*

- Decentralized Unitary System.
- Consists of indoor and outdoor units, suitable for cooling specific zones.

## 3. Multi-Split Air Conditioners:



*Figure 6 Multi-Split AC [8]*

- Unitary AC System with Multiple Indoor Units.
- Extension of split systems with multiple indoor units connected to one outdoor unit. Used in areas with similar cooling/heating zones.

## 4. Variable Refrigerant Flow (VRF) Systems:

- Centralized System with Variable Refrigerant Flow.
- Maintains variable refrigerant flow in indoor units, allowing independent control in different rooms. Energy-efficient with inverter compressors.



-Normally used in Malls and cinema halls.

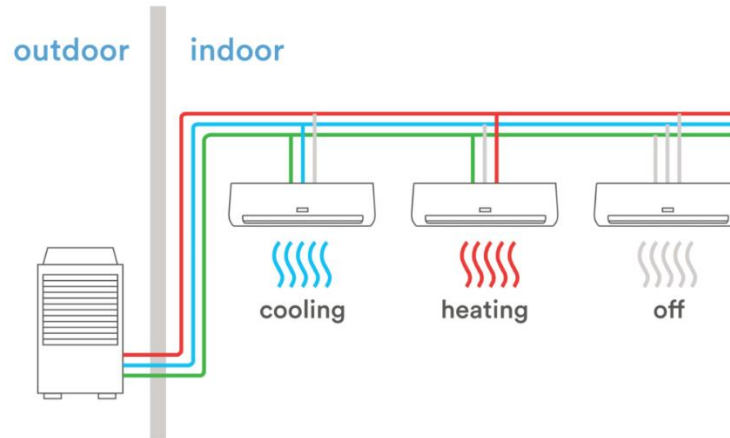


Figure 7 Schematic Diagram of VRF System [8]

**Benefits of VRF Systems:**

- High part-load efficiency.
- Enhanced comfort with precise temperature control.
- Design flexibility with multiple indoor units.
- Zoned comfort for different spaces.
- Lightweight and energy-efficient.

5. Air Handling Units (AHUs):

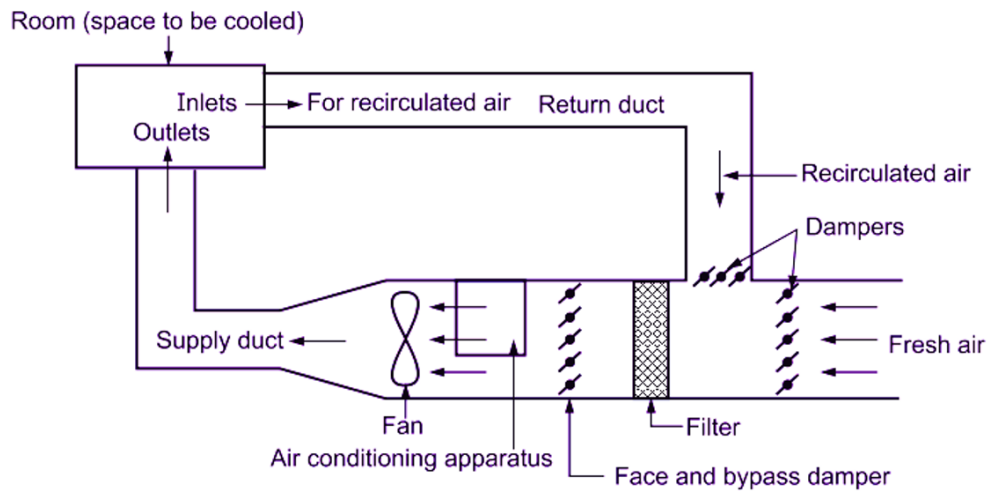


Figure 8 Air Flow Diagram [9]

-Indoor Air Conditioning and Distribution.

- Conditions and distributes air within a building. Components include grills, dampers, filters, and coils. Some units have heat recovery for energy efficiency.
- Heart of central air conditioning.
- AHU's supply fresh air to the room. The units take air from the outside, filter it and recondition it (cooled by a cooling coil or heated by a heating coil).

6. Chillers:

- Vapor Compression Refrigeration System.
- Central system for cooling with evaporator connected to process water. Uses chilled water circulated in air handling units or fan coil units. Types include air-cooled and water-cooled chillers.

7. Boilers for Heating:

- Hot Water Circulation for Heating.
- Provides hot water circulated directly into conditioned spaces or air handling units. Used for heating in HVAC systems.

8. Fan Coil Units:

- Indoor Units for Heating and Cooling.
- Consists of a coil for heating or cooling circulated air. Connected to a central system like a chiller or boiler.

### **3.3 Working Mechanism of HVAC System**

HVAC systems are responsible for regulating the temperature and air quality of indoor spaces. They consist of three main components: a heating unit, a cooling unit, and ducts for air circulation [2]. In order to maintain healthy air quality, HVAC systems require fans, blowers, filters, and ducts to circulate fresh air. In air conditioning, the unit draws air over evaporator coils filled with refrigerant, which extracts heat and cools the air. The refrigerant then undergoes compression and condensation in the compressor and condenser, expelling heat. The following components are involved in the working mechanism of the HVAC System [10]:

i. Thermostat:

The HVAC (Heating, Ventilation, and Air Conditioning) system is controlled by a thermostat that senses the temperature and humidity levels inside the building. If the temperature goes below or above the desired set point, the thermostat sends signals to the HVAC system to take appropriate actions. The thermostat acts as the control center for the HVAC system, ensuring that the settings are adjusted according to the indoor temperature and humidity levels.

ii. Air Intake and Filtration (AHU unit):

The HVAC system works by drawing in air from the surroundings. To ensure clean air, the air first passes through filters that trap dust, pollen, and other particulate matter, thus removing allergens. The AHU (Air Handling Unit) is responsible for circulating the filtered air throughout the building. It does this by drawing in the air from outside using a fan, filtering it, and then distributing it through ductwork to various parts of the building.

iii. Ventilation Process:

The system incorporates a ventilation process to ensure a continuous exchange of indoor and outdoor air. Stale indoor air is expelled, and fresh outdoor air is drawn in. This is crucial for maintaining indoor air quality.

iv. Heating Process:

If the indoor temperature is below the set point, the heating component is activated. This typically involves the use of a furnace, boiler, or heat pump.

The furnace burns fuel or the heat pump extracts heat from the external environment. The produced heat is then transferred to the air, warming it.

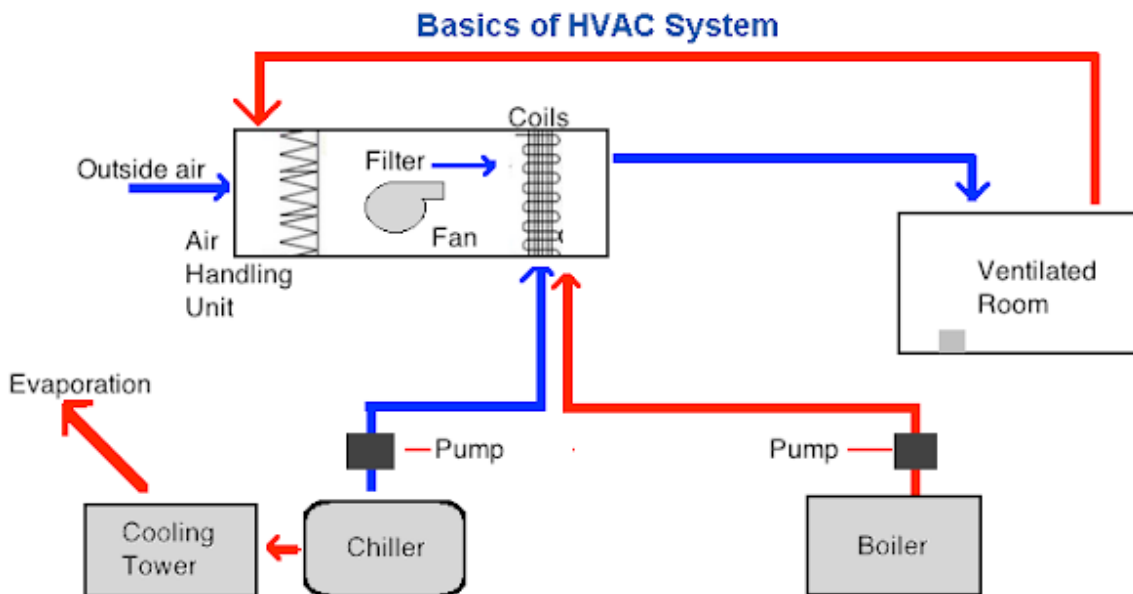


Figure 9 Schematic Diagram of HVAC Working Mechanism

v. Distribution through Ductwork:

The now-heated air is directed into a network of ducts. Ductwork acts as the transportation system, carrying conditioned air to various rooms within the building.

vi. Fans and Blowers:

Fans and blowers play a crucial role in the HVAC system. They are responsible for moving the air through the ductwork and into different areas of the building. This ensures the even distribution of conditioned air.

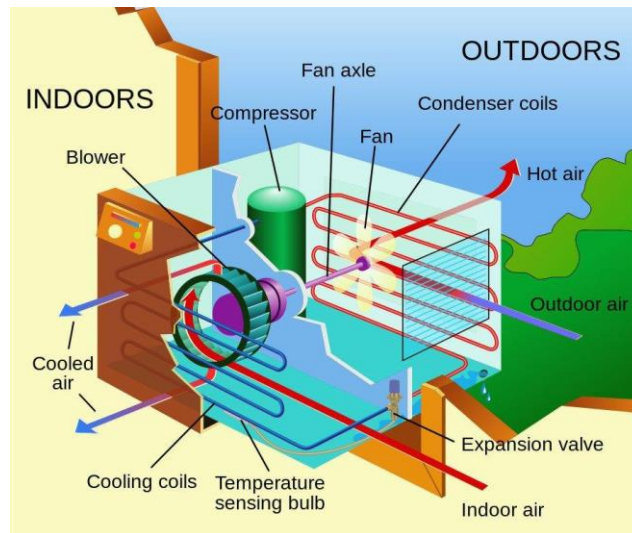
vii. Cooling Process (Air Conditioning):

If the indoor temperature is above the set point, the air conditioning component comes into play. This could involve the use of air conditioners, chillers, or cooling towers.

The air conditioning system extracts heat from the indoor air. It does this by circulating a refrigerant, which absorbs heat from the air, turning it into a gas.

viii. Compressor:

The refrigerant, which is now in a gaseous state, is pressurized and circulated by the compressor. This process increases the temperature of the refrigerant. The compressed refrigerant gas is then subjected to further compression by the compressor, which results in an increase in both its pressure and temperature. This gas, which is now at a high pressure and temperature, is then ready for the next stage.



*Figure 10 Air Conditioning Working Mechanism*

ix. Condensation and Release of Heat:

The refrigerant absorbs heat and carries it through the condenser coils. In the condenser, the refrigerant releases heat to the surrounding environment, causing it to condense back into a liquid form. This process is known as condensation. The condenser is responsible for converting the high-pressure vapor refrigerant into liquid refrigerant. Once the refrigerant is in its liquid state, it moves from the condenser through a component called the metering device or expansion valve.

x. Expansion and Evaporation:

The process of refrigeration involves the expansion of liquid refrigerant, which results in a reduction of both its pressure and temperature. This expansion takes place in the evaporator coils. As the refrigerant evaporates, it draws heat from the surrounding air, thereby cooling it down. The expansion valve, also known as the metering device, plays a vital role in regulating the flow of high-pressure liquid refrigerant to low-pressure liquid refrigerant before it is passed to the

evaporator. The HVAC system includes a component that converts the low-pressure vapor refrigerant to high-temperature vapor refrigerant, which absorbs indoor air, and the cycle of refrigerant movement restarts through the refrigerant lines.

xi. Ductwork and Distribution:

The cooled air is directed back into the building through the ductwork, which is a network of pipes and channels. This helps maintain a comfortable indoor temperature by distributing the cooled air to various rooms. The ducts are designed to ensure that the air flows smoothly and efficiently to all parts of the building.

xii. Humidity Control:

Some HVAC systems include components like dehumidifiers to control indoor humidity levels. This is crucial for achieving optimal comfort and preventing issues such as mold growth.

xiii. Air Return:

The process is completed with the return of the air to the HVAC system for recirculation. The cycle continues until the desired indoor conditions are achieved.

### **3.4 Installation and Assembly Considerations for HVAC Systems**

The installation and assembly considerations for HVAC systems are listed below [11]:

1. Selection of HVAC Equipment:

- Choose central HVAC air handling units (AHUs) serving multiple rooms when feasible, as they are quieter, less drafty, and easier to maintain.
- Specify features such as double-sloped drain pans, non-corroding materials, easy access doors, and tightly sealed cabinets for all air handling units.

2. Energy Recovery Ventilation:

- Consider incorporating energy recovery ventilation equipment to address indoor air quality (IAQ) concerns while balancing first cost, energy efficiency, and moisture control.

3. Location of Outdoor Air Intakes and Exhaust:

- Ensure proper placement of outdoor air intakes to minimize blockage and prevent the intake of contaminated air.
- Use sloped intake plenums and accessible intake screens to prevent blockage and allow for easy inspection and cleaning.
- Maintain adequate separation (at least 25 feet) from potential sources of air contaminants.
- Bird- and rodent-proof grilles protecting air intakes are essential to prevent operational disruptions and health risks.

4. Outdoor Air Quantity:

- Ventilate classrooms and other spaces according to the national consensus standard (ASHRAE Standard 62.1-2001), providing at least 15 cubic feet per minute (cfm) of outside air per occupant.
  - Implement demand-controlled ventilation systems in variable occupancy spaces, using sensors like carbon dioxide (CO<sub>2</sub>) sensors to adjust outdoor air quantities based on occupancy.
5. Air Filtration:
- Specify air filters with a dust-spot rating between 35% and 80% or a Minimum Efficiency Rating Value (MERV) of between 8 and 13 for effective protection of equipment and occupants.
  - Design systems with more filter surface area to reduce the frequency of filter changes, lower static pressure loss, and save energy.
  - Install pressure differential gauges across filter banks for easy monitoring and replacement.
6. Air Cleaning for Gaseous Contaminants:
- Manage and control potential pollution sources to reduce exposure to gases and volatile organic compounds (VOCs).
  - Use filters designed to remove gases and VOCs, considering the cost and maintenance implications.
7. Ventilation Controls:
- Specify measuring stations to actively control outdoor airflow by modulating outdoor air and return dampers.
  - Ensure proper pressurization of the building to prevent unexpected airflow and maintain IAQ.
8. Moisture and Humidity Control:
- Prevent uncontrolled moisture entry by addressing issues such as wet construction cavities, moisture-laden outdoor air, and condensation on cool surfaces.
  - Design for efficient drainage and consider moisture control strategies to protect against mold growth.
9. Air Distribution and Duct Insulation:
- Pay special attention to preventing moisture from entering ductwork to avoid mold growth.
  - Seal air ducts to prevent HVAC system air leakage, and ensure all components are easily accessible for maintenance.
10. Types of Air Distribution
- Investigate alternative methods like vertical displacement ventilation for energy efficiency and effective contaminant removal.
11. Exhaust Air:

- Provide exhaust ventilation for specific areas like janitor's closets, copy/work rooms, and arts/crafts preparation areas where concentrated pollutants may be present.
- Implement exhaust systems with differential pressure monitors to ensure proper building pressurization.

12. Designing for Efficient Operations and Maintenance:

- Ensure all system components are easily accessible for maintenance, with clear labeling for operations and troubleshooting.
- Facilitate access to air handling units, controls, and exhaust fans to streamline maintenance activities.

## 4. Detailed Description of Current and Recommended Maintenance Procedures

### 4.1 Objectives of Maintenance

The primary objectives of maintenance for HVAC systems are to ensure reliability, safety, and energy efficiency. Reliability is crucial for preventing unexpected failures that can disrupt operations. Safety is paramount, adhering to health and environmental regulations. Energy efficiency aims to optimize system performance, reducing operational costs and environmental impact.

### 4.2 Methodology Employed

The current methodology involves a reactive approach, addressing breakdowns as they occur. This often leads to higher costs and potential disruptions. The recommended approach shifts towards proactive maintenance strategies, including preventive, predictive, and reliability-centered maintenance [12].

- i. Corrective Maintenance (Current):
  - Reactive and unplanned.
  - Addresses breakdowns as they occur.
  - Measures the maintenance workforce based on the speed of response to failures.
- ii. Preventive Maintenance (Recommended):
  - Planned and scheduled in advance.
  - Involves routine inspections, cleaning, and component replacements.
  - Aims to prevent failures before they occur.
  - Enhances reliability and extends equipment life.
- iii. Predictive Maintenance (Recommended):
  - Condition-based approach.
  - Uses tools like vibration analysis, infrared thermography, ultrasonic testing, and motor current analysis.
  - Addresses issues based on indicators of decreasing performance.
  - Reduces downtime and extends equipment life.
- iv. Reliability-Centered Maintenance (Recommended):
  - System-focused rather than component-focused.
  - Emphasizes preserving system function.
  - Incorporates predictive maintenance techniques.
  - Systematically determines actions for continued desired performance.



### 4.3 Recommended HVAC Maintenance Procedure

According to HVAC manufacturing companies [13] [14], the following is the recommended HVAC maintenance procedure:

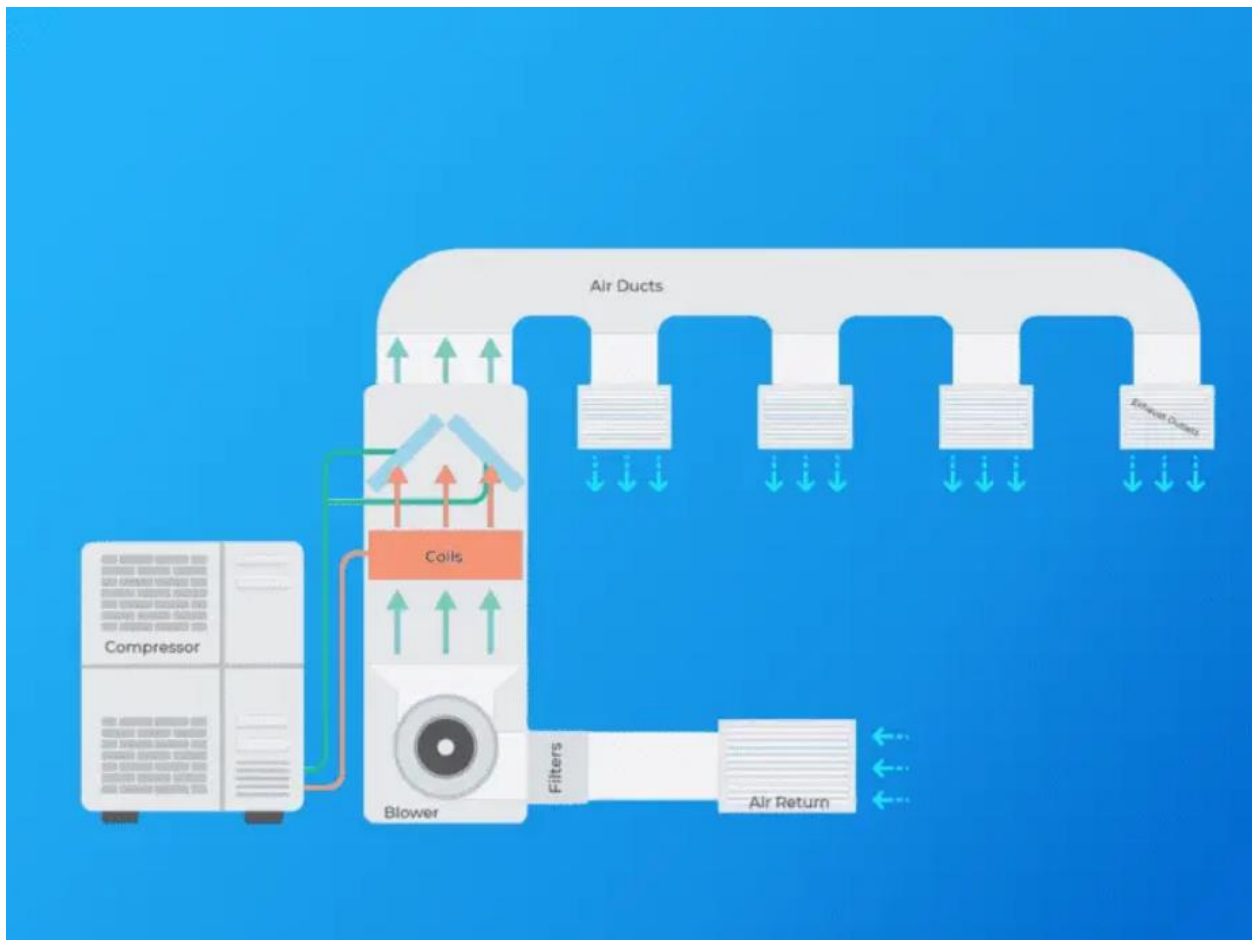
- i. Regular Scheduled Inspections:
  - Conduct bi-annual inspections, ideally in the spring and fall, to cover both heating and cooling seasons.
  - Schedule professional HVAC technicians to perform a comprehensive inspection of the entire system.
- ii. Thermostat Calibration and Settings:
  - Check and calibrate thermostats during each maintenance visit to ensure accurate temperature control.
  - Verify that programmable thermostats are set to optimize energy usage during different times of the day.
- iii. Electrical Components Inspection:
  - Tighten electrical connections and inspect wiring for damage.
  - Ensure that all electrical components are in good condition and replace any faulty parts.
- iv. Lubrication of Moving Parts:
  - Lubricate all moving parts such as fans, motors, and bearings to reduce friction and improve efficiency.
- v. Condensate Drain Maintenance:
  - Inspect and clean the condensate drain to prevent clogs, water damage, and microbial growth.
- vi. System Controls Check:
  - Verify the proper functioning of system controls, including safety controls and start cycle.
- vii. Blower Components Cleaning and Adjustment:
  - Clean and adjust blower components to maintain optimal airflow and system efficiency.
- viii. Evaporator and Condenser Coil Cleaning:
  - Clean evaporator and condenser coils to remove dirt and debris, ensuring efficient heat exchange.
- ix. Refrigerant Charge Check:
  - Verify the refrigerant charge to ensure it is at the correct level for efficient cooling.

x. Fuel Line Inspection:

- Check fuel line connections for leaks and ensure proper fuel supply for heating systems.

xi. Inspection of Gas Pressure, Burner Combustion, and Heat Exchanger:

- Inspect gas pressure, burner combustion, and the heat exchanger to ensure safe and efficient operation.



*Figure 11 HVAC System Maintenance [14]*

xii. Filter Replacement:

- Change HVAC filters regularly, approximately every 30 days, to maintain good indoor air quality and system efficiency.

xiii. Visual Inspection of HVAC System:

- Conduct a visual inspection of the entire HVAC system, including the thermostat, indoor and outdoor units, registers, and returns, to identify potential issues.

- xiv. Removal of Clutter Around Indoor HVAC Unit:
  - Ensure the area around the indoor HVAC unit is clear of clutter to improve air circulation, safety, and system efficiency.
- xv. Outdoor Unit Maintenance:
  - Keep the outdoor unit clean and clear of debris to maintain proper airflow and prevent system strain.
- xvi. Temperature Regulation Practices:
  - Encourage occupants to operate HVAC systems at comfortable temperatures and consider installing programmable thermostats for energy-efficient temperature control.
- xvii. Battery Replacement in Thermostat:
  - Replace thermostat batteries at least once a year to prevent operational issues.
- xviii. Carbon Monoxide Detector Maintenance:
  - Test carbon monoxide detectors monthly, replace them every seven years, and change batteries semi-annually
- xix. Monitoring Energy Bills:
  - Regularly monitor energy bills and investigate any unusual spikes in consumption to identify potential HVAC issues.
- xx. Total Replacement Planning:
  - Develop a plan for total HVAC system replacement when the existing system approaches the end of its expected lifespan, typically between 15 and 25 years.

#### **4.4 HVAC Routine Maintenance Considerations:**

HVAC system requires regular maintenance to function properly, avoid energy waste, and stay clean. A good maintenance program should follow this checklist [15]:

- i. Filter Inspection:
  - Ensure all filters are clean and in place.
  - Use efficient filters for optimal system performance.
- ii. Control System Maintenance:
  - Check the controls for proper operation.
  - Periodically calibrate controls and clean contacts.
  - Prevent pitting and carbonization.
- iii. Instrument Operation Check:
  - Inspect instrument bellows and contacts for satisfactory operation.

- Verify the expansion or contraction of bellows or diaphragms.
- iv. Smooth Operation of Linkages:
  - Ensure linkages operate smoothly throughout their full range.
- v. Air Balancing Check:
  - Verify proper air distribution.
  - Ensure dampers and valves provide the correct flows.
- vi. Energy-Efficient Operation:
  - Check time clocks and programmed schedules to reduce equipment run-time.
  - Utilize energy management system data tracking for efficient operation.
- vii. Heat Transfer Surface Cleaning:
  - Clean heating and cooling coils to remove dirt.
  - Ensure all heat transfer surfaces are clean, including coils and heat exchangers.
- viii. Evaporator Maintenance:
  - Keep the outside air intake for indoor evaporators free of debris.
  - Regularly clean filters and, if necessary, use solvents or degreasers to remove accumulated grease and dirt.
- ix. Condenser Coil Cleaning:
  - Keep the condenser coil clean for efficient heat transfer.
  - Rinse with a garden hose occasionally when the unit is not running.
- x. Condenser fan maintenance:
  - Keep the condenser fan and coil free of debris for maximum airflow.
  - Lubricate condenser fan motors as needed.
- xi. Drive System Efficiency Check:
  - Align and adjust belts for optimal efficiency.
  - Check the motor power factor and efficiency.
- xii. Chiller, Cooling Tower, and Boiler Service:
  - Service according to manufacturers' procedures.
- xiii. Utilize Free Cooling:
  - Set cooling equipment control parameters for maximum efficiency during the spring.
- xiv. Insulation Check:
  - Inspect and ensure proper insulation on all cool surfaces, including refrigeration and chilled water lines.
- xv. Cooling Tower and Air-Cooled Condenser Cleaning:
  - Clean up sludge regularly.

- xvi. **Belt Inspection:**
  - Ensure all belts are in good shape and not slipping.
- xvii. **Motor Lubrication:**
  - Properly lubricate all system motors.
- xviii. **Gas furnace maintenance:**
  - Replace or wash filters monthly.
  - Clean the humidifier if it is equipped.
  - Check for black soot, indicating an incorrect air mixture.
- xix. **Humidifier Cleaning:**

Use a vinegar and water mixture to clean mineral deposits.
- xx. **Water Drainage Check:**
  - Ensure proper drainage of equipment.
- xxi. **Duct Inspection:**
  - Check ducts for air leaks and repair them with UL-logo duct tape.
- xxii. **Vapor Barrier Check:**
  - Ensure a well-sealed vapor barrier exists on the outside of cooling duct insulation.
- xxiii. **Cooling Water Quality Check:**
  - Initiate a proper chemical treatment program.
- xxiv. **Chiller Maintenance:**
  - Review and evaluate log readings.
  - Test for leaks.
  - Drain oil, remove samples for analysis, and change oil, filters, and strainers as needed.
  - Perform various tests on compressor motor windings.
- xxv. **Evaporator and Condenser Maintenance:**
  - Drain water, clean or brush tubes, evacuate the machine to dehydrate, and perform tests.
- xxvi. **Supply, Return, and Exhaust Fan Maintenance:**
  - Check fan operation, bearings, belt tightness, and the temperature of the supply air.
  - Inspect v-belts, seismic snubbers, and spring isolators.
  - Grease bearings, inspect motor starters and wiring, and check the amperage and voltage of motors.
  - Clean fans and scrolls, and replace filters.

## 5. Maintenance and Inspection Checklist

A heating, ventilation, and air conditioning (HVAC) maintenance checklist is a systematic list of tasks designed to assist maintenance technicians in assessing and repairing HVAC systems. The table below represents the basic maintenance checklist for checking how the HVAC system is working and whether any faults are present.

*Table 1 HVAC Sample Maintenance and Checklist*

### HVAC Maintenance Checklist

<b>Location</b>		
<b>Building</b>		
<b>Completed By</b>		
<b>Date</b>		
<b>Task</b>	<b>Comment</b>	<b>Done</b>
<b>Regular Filter Replacement</b>	<b>Check and replace air filters every 1-3 months</b>	
<b>Thermostat Maintenance</b>	<b>Inspect and calibrate the thermostat</b>	
<b>Indoor Unit Inspection</b>	<b>Check for any visible signs of damage or leaks</b>	
<b>Outdoor Unit Maintenance</b>	<b>Remove any debris, leaves, or vegetation</b>	
<b>Condensate Drain Cleaning</b>	<b>Clear the condensate drain line</b>	
<b>Check Electrical Connections</b>	<b>Inspect electrical connections, wiring, and components</b>	
<b>Lubricate Moving Parts</b>	<b>Lubricate motor bearings and other moving parts</b>	
<b>Check Refrigerant Levels</b>	<b>Monitor refrigerant levels</b>	
<b>Test System Performance</b>	<b>Run a test cycle</b>	
<b>Schedule Professional Maintenance</b>	<b>Annual or bi-annual maintenance visits</b>	

An HVAC inspection checklist is the most useful HVAC technician tool. It ensures that they inspect all major components of the HVAC system. A good HVAC inspection checklist should include tasks like [16]:

- Checking the filters and replacing them if necessary
- Inspecting the coils for dirt or damage
- Checking the wiring for signs of corrosion or damage
- Checking the refrigerant levels
- Inspecting the ducts for leaks or damage
- Checking the ventilation system for proper airflow

# HVAC Checklist - Long Form

Building: \_\_\_\_\_ File Number: \_\_\_\_\_

Completed by: \_\_\_\_\_ Title: \_\_\_\_\_ Date Checked: \_\_\_\_\_

Component	OK	Needs Attention	Not Applicable	Comments
<b>Face and Bypass Dampers</b>				
Damper operation correct?				
Damper motors operational?				
<b>Cooling Coil</b>				
Inspection access?				
Clean?				
Supply water temp. _____°F				
Water carryover?				
Any indication of condensation problems?				
<b>Condensate Drip Pans</b>				
Accessible to inspect and clean?				
Clean, no residue?				
No standing water, no leaks?				
Noticeable odor?				
Visible growth (e.g., slime)?				
Drains and traps clear, working?				
Trapped to air gap?				
Water overflow?				

Figure 12 HVAC Inspection Checklist [16]

## 6. Condition Monitoring Techniques

Monitoring the condition of HVAC (Heating, Ventilation, and Air Conditioning) systems is essential to ensure they perform optimally, are energy efficient and have a long lifespan. There are several techniques that can be used to monitor the health and performance of an air conditioning system. Here are some key techniques:

### 6.1 Vibration Analysis:

To detect mechanical issues in rotating equipment, such as compressors and fans, vibration sensors are placed on critical components. Variations in vibration patterns can indicate misalignments, imbalances or bearing wear.



*Figure 13 Vibration Analyzer- Falcon [17]*

### 6.2 Temperature Monitoring:

The purpose of this process is to detect any unusual temperature patterns that may indicate problems with the refrigeration cycle or its components. To achieve this, temperature sensors are installed on different parts of the system. Any deviations from the normal temperature ranges will be closely monitored as they can be indicative of potential issues.





*Figure 14 Infrared thermography [17]*

### **6.3 Pressure Monitoring:**

To ensure proper levels of refrigerant pressure and identify issues in the system, pressure sensors are placed at key points in the refrigeration cycle to help diagnose problems such as low refrigerant levels or blockages.

### **6.4 Filter Differential Pressure Monitoring**

To ensure that air filters are functioning properly, differential pressure sensors across filters monitor pressure drop. A significant increase may indicate the need for filter replacement.

### **6.5 Energy Consumption Analysis:**

To evaluate the energy efficiency of the HVAC system, energy meters and sensors are utilized to monitor its power consumption, detecting any inefficiencies or malfunctions.

### **6.6 Real-time monitoring systems:**

To enable continuous, remote monitoring of the HVAC system, sensors and IoT technology are utilized to provide real-time data on various parameters, triggering alarms for abnormal conditions.

### **6.7 Fluid Analysis:**

Samples of lubricating fluids from compressors are analyzed for contaminants, wear particles, and chemical composition, providing insights into the condition of the system.



*Figure 15 Illustration - Oil Analysis [17]*

### **6.8 Infrared Thermography:**

To detect hotspots and insulation issues, infrared cameras capture temperature variations in electrical components.

### **6.9 Comprehensive Building Management Systems (BMS):**

To incorporate HVAC monitoring into a comprehensive building management framework, BMS platforms gather data from various sensors for centralized control, analysis, and reporting.

### **6.10 Routine Visual Inspections:**

To detect problems early, trained technicians perform regular inspections to identify visible signs of wear, leaks, or other issues that may not be immediately apparent through other monitoring techniques.

## 7. Corrosion Danger and Prevention Techniques

To maintain optimal building conditions, it is crucial to ensure that HVAC systems operate efficiently and last for a long time. However, corrosion poses a significant challenge to HVAC systems, which can lead to operational inefficiencies, increased costs, and potential system failures if left untreated. In this comprehensive maintenance report, we will assess the risks of corrosion in HVAC systems and explore the techniques used for effective corrosion prevention.



*Figure 16 Corrosion on AC Coil [18]*

### 7.1 Corrosion Risks in HVAC Systems

#### I. Water-Based Corrosion:

Condenser water systems can be prone to galvanic corrosion, particularly in tube sheet heat exchangers that are made with dissimilar metals due to the presence of water in cooling towers. In chilled water systems, there can be corrosion in chillers and heat exchangers caused by contact with water, which can result in the gradual loss of metal over time.

#### II. Environmental Factors:

Air handling units and ductwork can experience internal corrosion due to factors such as water condensation, high temperatures, aggressive cleaning agents, and microbiological growth.

### 7.2 Techniques for Corrosion Prevention

#### • Material Selection:

When designing condenser water and chilled water systems, it is important to use materials that are resistant to corrosion. For condenser water systems, it is recommended to use materials like stainless steel or coated metals in critical components. For chilled water systems, epoxy coatings should be utilized to protect tube sheets and prevent corrosion.

#### • Protective Coatings:

Air Handling Units and Ductwork should have corrosion-resistant coatings applied to their internal and external surfaces, considering the complex geometries of ductwork. Additionally, condenser

and chilled water systems can be protected from corrosion by coatings with excellent adhesion and resistance to chemicals.

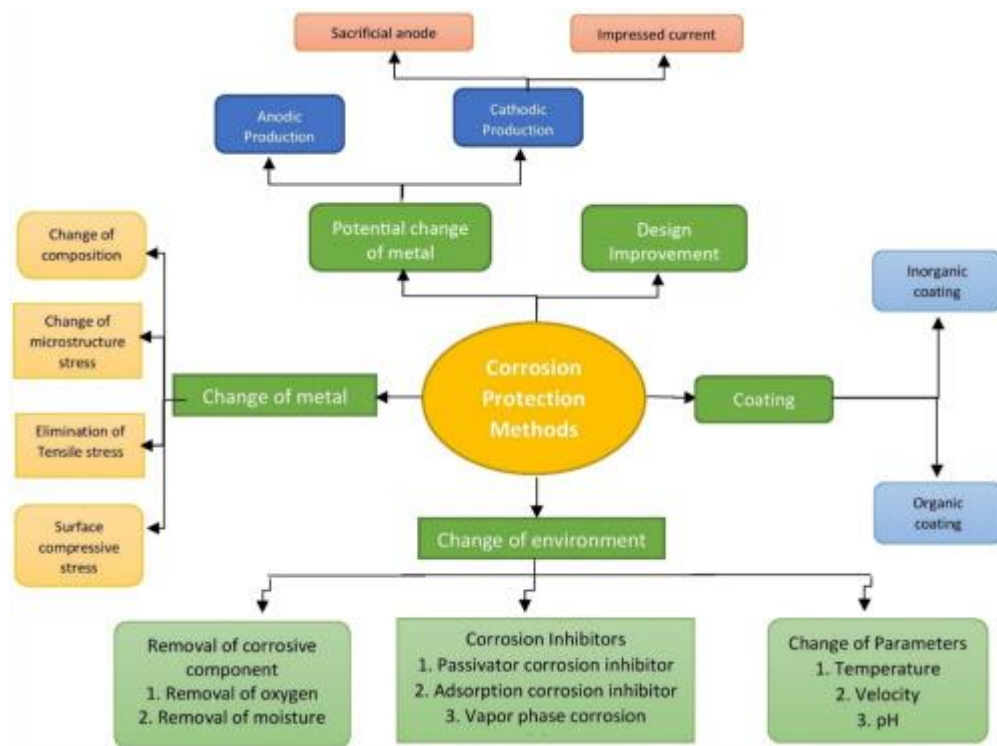


Figure 17 Corrosion Prevention Techniques [19]

- **Routine Inspection and Maintenance:**

It is recommended to regularly inspect HVAC components that are prone to corrosion, such as tube sheets, coils, and duct seams. Implementing a proactive maintenance schedule can help identify and address any corrosion issues quickly.

- **Water Treatment:**

Implement effective water treatment programs to maintain optimal water quality and pH levels, reducing the risk of corrosion. Regularly monitor and adjust chemical treatments to ensure corrosion prevention.

- **Cathodic Protection:**

Galvanic corrosion in systems with dissimilar metals can be mitigated by implementing sacrificial anodes or impressed current cathodic protection. Regular inspection and replacement of sacrificial anodes should be part of preventive maintenance.

- **HVAC System Design Considerations:**

It is essential to ensure proper drainage in air handling units to prevent water accumulation, which can cause corrosion. Additionally, systems should be designed with accessibility in mind to facilitate easier inspection and maintenance.

- Corrosion Inhibitors:

As part of regular maintenance, incorporate corrosion inhibitor programs to disrupt anode reactions and decelerate cathodic reactions. Utilize inhibitors during system cleaning and pretreatment phases to enhance protection.

## 8. Failure Analysis in HVAC Systems

### 8.1 Introduction

Analyzing failures in HVAC (Heating, Ventilation, and Air Conditioning) systems is an important part of their maintenance reports. It is crucial to understand the possible causes of failures and provide detailed descriptions for effective troubleshooting and reliable performance of the system. This section covers the common causes of failure and provides in-depth descriptions of these failures.

### 8.2 Possible Causes of Failure

- Faulty Circuit Breaker or Fuse

The HVAC system may fail due to a malfunctioning circuit breaker or blown fuse. This often requires the replacement of the fuse or resetting the breaker after allowing the system to cool down for 15 minutes.

- Refrigerant Leak

Inadequate refrigerant levels can cause improper operation, while leaks are harmful to the environment and require a licensed technician to repair and recharge the system.

- Frozen Coil

Air filters should be cleaned or replaced regularly to prevent airflow problems that can cause a frozen coil.

- Damaged Fan Blades, Compressor, Electrical Connections, and Contacts

Aging systems are prone to worn or damaged components, such as fan blades, compressors, electrical connections, and contacts. Annual maintenance can help identify and address these issues.

- Neglecting Annual Maintenance

Regular annual maintenance is crucial to ensure the optimal performance of your HVAC system. Licensed technicians can identify potential problems before they escalate, ensuring the reliability and longevity of your system.

- Faulty Thermostat

A malfunctioning thermostat can cause the air conditioner to cycle frequently or fail completely. Regular inspection and upgrading to modern thermostats is advisable.

### **8.3 Description of Failures**

- Understanding the Root Cause

Root cause analysis is essential to failure analysis. It involves gathering information to determine whether failures occurred due to manufacturing defects, material issues, or misuse.

- Taking Corrective Action

Preventing the recurrence of problems is crucial and often requires redesigning the product or reviewing usage parameters.

- Improving Future Products

Learning from past failures helps prevent future problems, legal issues, and safeguards reputation and safety in manufacturing processes and product designs.

- Preventing Financial Losses

Failure analysis helps prevent costly outages, production halts, and legal action.

- Ensuring Compliance with Standards

Failure Mode and Effects Analysis (FMEA) helps ensure that components meet manufacturing standards, contributing to overall product reliability.

- Accountability for Failure

Failure analysis helps to determine the cause of failure and assign responsibility. This information can be crucial in legal proceedings.

### **8.4 Failure Analysis Tools**

#### *8.4.1 Fault Tree Analysis (FTA)*

FTA is a tool that uses Boolean logic to identify component-level failures and their impact on system-level failure.

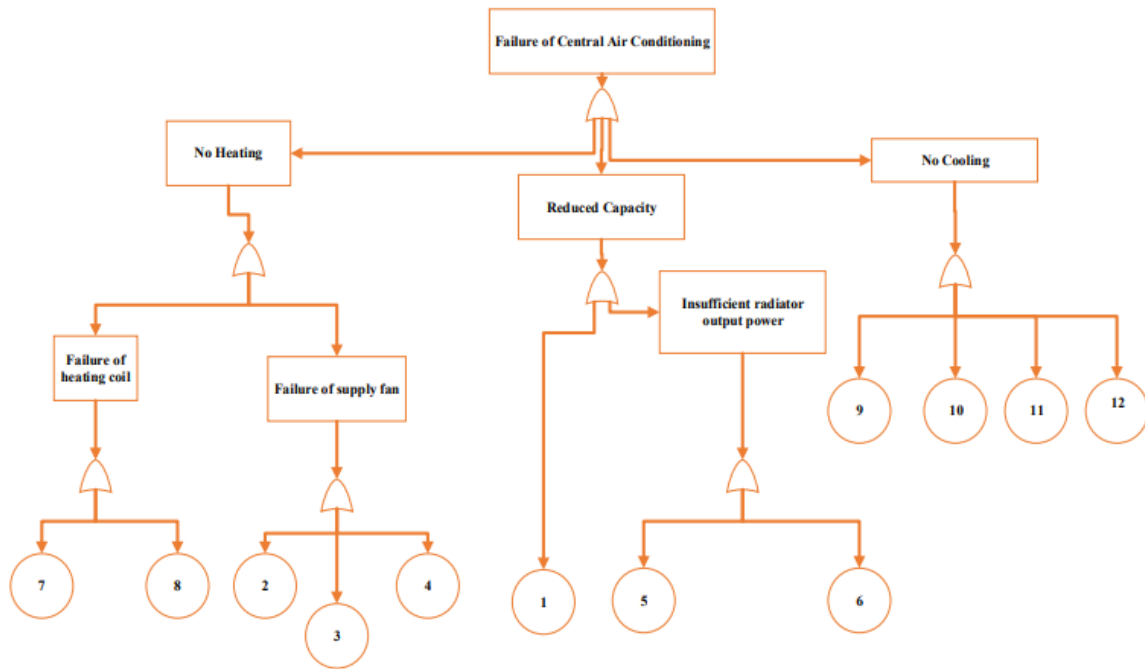


Figure 18 FTA of HVAC System [20]

#### 8.4.2 Failure Mode and Effect Analysis (FMEA)

FMEA is a systematic and qualitative analysis tool that helps anticipate potential failures in products or processes. It aids in identifying the causes, effects, and the likelihood of detection of failures before they occur.

Sample FMEA table for HVAC system is shown in table below:



Table 2 HVAC System FMEA Table

S.N.	Component/Process	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Probability of Occurrence (P)	Probability of Detection (D)	Risk Priority Number (RPN)	Recommended Actions	Responsible Party	Status
1	Air Handling Unit (AHU)	Fan Motor Failure	Insufficient air circulation, leading to inadequate ventilation and temperature control Reduced cooling capacity, potential environmental impact	5	3	2	30	Regular motor inspections and replacement schedule	Maintenance Team	In Progress
2	Condenser Unit	Refrigerant Leak	Uneven temperature distribution, increased energy consumption	4	2	3	24	Periodic leak checks and prompt repairs	HVAC Technician	Completed
3	Ductwork	Blocked Air Flow	Inaccurate temperature control, discomfort for occupants	3	3	2	18	Regular inspection and cleaning of ducts	Maintenance Team	Planned
4	Thermostat	Sensor Malfunction		4	2	4	32	Calibration checks and sensor replacement	HVAC Technician	In Progress

## 9. Tools and Equipment for Inspection, Maintenance, and Monitoring of HVAC Systems

The smooth functioning and durability of HVAC systems are highly dependent on thorough inspections, proactive maintenance, and effective monitoring. Having a comprehensive set of tools and equipment specifically designed for these purposes is crucial to ensure optimal performance. This overview aims to provide insights into the necessary tools used in inspecting, maintaining, and monitoring air conditioning systems.

### 9.1 Inspection Tools [21]:

#### I. Combustible Gas Leak Detector:

Purpose: Designed for residential and small commercial applications.



*Figure 19 Combustible Gas Leak Detector [22]*

Application: Semiconductor sensor for accurate detection of combustible gases. Features an 18-inch flexible detector wand for pinpointing leaks.

#### II. Air Quality Meter:

Purpose: Ideal for Indoor Air Quality (IAQ) diagnostics.

Application: Measures CO<sub>2</sub> and CO levels, air temperature, dew point, wet bulb temperature, and humidity. Utilizes nondispersive infrared (NDIR) technology.



Figure 20 PCE-RCM-10, Air Quality Meter [23]

### III. True RMS HVAC/R Clamp Meter:

Purpose: Applied to motor or line currents, controls voltage, and performs system board voltage checks.

Application: Quick check of live wires, circuit continuity, and specified resistance.

### IV. Honeywell Transmission Risk Air Monitor Bundle:

Purpose: Monitors CO2 levels in small-to-medium-sized buildings.

Application: Alerts users to conditions increasing the risk of exposure to airborne viral transmission. Proprietary technology with user-controlled settings.

### V. Additional Inspection Tools for Air Conditioning Maintenance:

Gauge Manifold, Digital Clamp Multi Meter, Nose Plier, Screw Driver, Screw Wrench, L Key Set, Vacuum Pump, Mini Gas Welding Machine, Torch, Swaging Tool, Level, Oil Filter Wrench, Tubing Cutter, Tube Bender (Manual), Drill Machine, Measuring Tape, Pipe Cutter, Hammer, Wire Cutter, Flashlight/Headlamp, Core Removal Tool.

## **9.2 Monitoring Tools:**

### I. Anemometers:

Purpose: Measures speeds and directions of both wind and gas.

Application: Handheld hot-wire anemometers are common for HVAC jobs, while vane-styled anemometers are used outdoors.

## II. Balometers (Airflow Capture Hoods)

Purpose: Measures the volume of air being exerted out of grilles and diffusers.



*Figure 21 Airflow Instruments ProHood Capture Hood PH731 [24]*

Application: Digital tools for accurate recording and adjustment to different size grilles and diffusers.

## III. Duct Leakage Testers:

Purpose: Measures the airtightness of forced air HVAC ductwork.

Application: Provides step-by-step test configuration based on industry standards, ensuring accurate results.

## IV. Hygrometer:

Purpose: Measures the amount of humidity (water vapor) in the air.



*Figure 22 Cigar Oasis Caliber 4R Digital/Analog Hygrometer [25]*

Application: Essential for monitoring air quality and preventing issues related to leakage and water damage.

V. Borescope (Distance Meter):

Purpose: Measures distances like length, volume, and more.

Application: Bluetooth-friendly devices that enhance precision during complex HVAC installations.

## **10. Safety Hazards and Precautions in HVAC System Maintenance**

Safety is paramount in the HVAC industry, especially during the installation, operation, inspection, and maintenance of HVAC systems. Identifying potential safety hazards and implementing recommended precautions are critical to ensuring the well-being of technicians and the efficient functioning of the systems. The common safety hazards and essential precautions for HVAC system maintenance are listed below [26].

### **10.1 Safety Hazards**

#### **1. Electrical Hazards**

##### Identification:

- Exposed wiring during maintenance.
- High-voltage components in HVAC units.

##### Precautions:

- Ensure proper lockout/tagout procedures are followed.
- Use appropriate personal protective equipment (PPE) like insulated gloves and safety goggles.
- Verify circuits are de-energized using voltage testers before starting work.

#### **2. Refrigerant Exposure**

##### Identification:

- Potential leaks or releases of refrigerants.
- Inhalation risks during maintenance.

##### Precautions:

- Adhere to Environmental Protection Agency (EPA) guidelines for refrigerant handling.
- Wear recommended respiratory protection.
- Regularly check for leaks and repair promptly.

#### **3. Falls from Heights**

##### Identification:

- Working on rooftops, ladders, or elevated platforms.

##### Precautions:

- Use fall protection equipment, including harnesses and lanyards.
- Ensure ladders are secure and placed at proper angles.
- Work in well-lit areas without tripping hazards.

## 4. Chemical Hazards

### Identification:

- Use of cleaning agents or chemicals during maintenance.

### Precautions

- Work in well-ventilated spaces.
- Wear appropriate PPE, including chemical-resistant gloves and aprons.
- Read and follow safety data sheets (SDS) for all chemicals.

## 5. Equipment Malfunctions

### Identification:

- Wear, tear, or malfunction of HVAC components.

### Precautions:

- Regularly inspect equipment for damage.
- Follow manufacturer guidelines for maintenance.
- Ensure safety guards and devices are in place and functioning.



*Figure 23 Maintenance of Air Conditioning [26]*

## 6. Emergency Situations

### Identification:

- Unforeseen emergencies such as fire or system failures.

## Precautions:

- Be familiar with emergency response procedures.
- Ensure easy access to first aid kits and fire extinguishers.
- Conduct regular emergency drills.

### **10.2 Recommended Precautions**

#### **1. Training and Certification**

- Ensure all technicians are adequately trained and certified.
- Provide ongoing training to keep technicians informed about the latest safety protocols.

#### **2. Pre-Job Site Assessment**

- Conduct a thorough assessment of the job site for potential hazards.
- Identify confined spaces or unusual working conditions before initiating work.

#### **3. Personal Protective Equipment (PPE)**

- Make PPE, such as safety glasses, gloves, and respiratory protection, mandatory.
- Regularly inspect and replace damaged PPE.

#### **4. Lockout/Tagout Procedures**

- Implement strict lockout/tagout procedures to de-energize equipment during maintenance.
- Clearly communicate the status of equipment using standardized tags.

#### **5. Regular Inspection and Maintenance**

- Establish a routine inspection schedule for HVAC systems.
- Regularly check for leaks, wear, and tear in components.
- Address issues promptly to prevent malfunctions.

#### **6. Chemical Handling Protocols**

- Provide training on the proper handling and storage of chemicals.
- Store chemicals in well-labeled containers in designated areas.

#### **7. Emergency Response Plan**

- Develop and communicate a comprehensive emergency response plan.
- Conduct regular drills to ensure all technicians are familiar with emergency procedures.

#### **8. Documentation and Reporting**

- Implement a robust documentation system for all maintenance activities.
- Encourage technicians to report near-misses or potential hazards promptly.



## 11. Conclusion

This report provides maintenance information for HVAC systems, which are important in various applications. It explains the principles of HVAC systems and the fundamentals of maintenance engineering. The report also covers current and recommended maintenance procedures, including objectives, methodologies, routine considerations, and comprehensive checklists.

The report includes information on condition-monitoring techniques, such as vibration analysis, temperature monitoring, and real-time monitoring systems. These techniques are important for proactive maintenance, as they help identify potential issues before they become failures.

The report also addresses the risks of corrosion in HVAC systems, providing insights into the associated dangers and prevention techniques. It emphasizes the importance of failure analysis, which can help understand the causes of potential failures.

The report provides information on essential inspection and monitoring tools for HVAC maintenance. It also explores safety hazards and recommended precautions, highlighting the importance of technician safety and the need for preventive measures to mitigate potential risks.

In conclusion, this report is a valuable resource for HVAC professionals, emphasizing the holistic approach required for the efficient and safe functioning of HVAC systems. By integrating routine maintenance practices, advanced monitoring techniques, and a robust understanding of safety protocols, HVAC systems can be sustained at optimal performance, contributing to enhanced energy efficiency, prolonged equipment lifespan, and the overall well-being of both the systems and the professionals involved.

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