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Reliability Centered Maintenance (RCM) of a Commercial HVAC Air Handling and Condensing Unit

Sohaib Ahmed, Muhammad Asif and Asad A. Zaidi

Department of Engineering Sciences, PNEC, National University of Science and Technology, Islamabad, Pakistan
asadali@pnec.nust.edu.pk

ABSTRACT

Reliability Centered maintenance (RCM) procedure was suggested for HVAC system of a recently established forensic laboratory at ICCBS, Karachi. The system comprises of three major components; 1.) Air Handling Unit 2.) Condensing Unit 3.) Thermostat Box. RCM decision and information worksheet along with detailed preventive maintenance plan was proposed for the HVAC system. A trained HVAC maintenance team is needed to implement RCM strategy to prevent early failures and ensure 24/7 availability of the HVAC System.

Key words: HVAC, RCM, Reliability, Maintenance, Preventive Maintenance

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INTRODUCTION

Reliability Centred Maintenance (RCM) is a process to determine the maintenance requirements of any asset/machinery under its optimal operating conditions [1–4]. It is a process that is completed to make sure that all the machinery and assets perform as desired by their users with optimum efficiency. The strength of RCM lies in the fact that it can be applied to any process no matter its size [5–8]. It can be applied to a nuclear facility, automotive industry and it can even be applied to airplane maintenance or just any individual machinery in the facility. RCM can be used to develop scheduled and proactive maintenance procedures, redesigning of equipment, improve troubleshooting procedures hence increasing the overall efficiency of the process and reducing its cost[9]. Therefore, RCM is a structured process that is used to determine failure modes and develop strategies to overcome them, under operation requirements and effective cost [10–12].

Recently Sindh Government has set up a forensic laboratory at Karachi University, ICCBS to examine criminal evidence from across the province [13]. It has been established as per international standards and all the technical staff has been trained to carry out DNA analysis for the provided sample. As per Forensic Laboratory handbook, air handling units have been installed to provide filtered, conditioned air so that the working environment can be maintained as per user specifications.

A total of ten air handling units have been installed across different labs in the forensic facility. Two critical labs have 100% redundant HVAC system i.e. two air handling units paired with condensing units that are connected to the Building Management System (a PLC based control system) which continuously monitors both the system that is running and one on standby. In case one unit breaks down it automatically shifts to the other one and vice versa. The BMS system makes sure that the lab is available for 24 hours a day even if one HVAC system breaks down.

The purpose of AHU HVAC system is to maintain the temperature, humidity and differential pressure of a certain zone within desirable limits, it comprises of three main components:

Air Handling Unit (AHU):

The Air handling unit is an assembly of different components that are divided into the following sections:

- Return air mixing section
- Aluminum filter section
- 65% bag filter section
- Motor & blower section
- Cooling coil

- 95% bag filter section
- Discharge plenum

Condensing Unit (CUN)
They are responsible for pumping heat from low temperature reservoir to a high temperature reservoir. They consist of following major components:

- Compressor
- Condenser fan
- Condenser fan motor
- Condenser coils
- Electrical panel (capacitors, contactors, power monitor, fuses, relays, thermal overloads etc.)
- Refrigeration component accessories (high/low refrigerant pressure sensors etc.)

Thermostat box
It serves as the brain or control unit for the entire HVAC system, providing communication and seamless control between air handling unit and condensing unit to ensure operation in different weather conditions. It consists of following major components:

- Temperature sensors
- AHU starter relay
- Compressors start relay
- Condenser fan motor start relay
- High/low pressure relays
- LCD screen
- Control Circuit

FUNCTIONS OF HVAC SYSTEM

Functions of Air Handling Unit (AHU)
The supply and return air sections of the ahu are connected via ducts to supply conditioned and filtered air to the respective zone. The room air is pumped into the return air mixing chamber of the ahu where some fresh air is added via fresh air damper that is connected to the return air mixing chamber. This mixture of return and fresh air then passes through a series of three filters: 1.) Aluminumprefilters 2.) 65% bag filters 3.) 95% bag filters. After two stage of filtration the dust particles present in the air are removed with an efficiency of about 70-80% as per U.S Ashrae Ratings. After the initial filtration process the air is pumped into the blower section, where a motor is connected to a centrifugal blower via belt & pulley arrangement. The blower pumps the air through the entire centralized ducting system. After the blower section the air is expanded by a diffuser plate so that it can travel uniformly through the cooling coil. The cooling coil cools and dehumidifies the incoming air so that required temperatures can be achieved. After the cooling coil, the air passes over 95% bag filters which removes fine particles suspended in air with an efficiency of 95% for 0.4μm particles. Finally, the air is pumped into the discharge plenum which is connected to the central ducting system. The filtered and conditioned air then enters the particular zone to maintain the required temperatures, humidity levels and differential pressures.

Functions of Condensing Unit (CUN)
Condenser is designed to exchange heat between the working fluid (refrigerant) and the atmosphere. The basis of working of a condensing unit is a simple vapor compression cycle. The gaseous refrigerant is pumped by the compressor such that it has a higher temperature than the surrounding atmosphere, this heated refrigerant is pumped through the condenser coil where forced air ventilation driven by condenser fan motor allows the refrigerant to reject heat into the surroundings. The refrigerant rejects all latent heat and becomes saturated liquid, this liquid is throttled to a low temperature and pumped into the AHU where it cools the surrounding air by absorbing heat and becomes saturated vapor, this vapor is then passed into the compressor and the cycle continues.

Function of Thermostat box
The thermostat or operation box controls the entire operation of HVAC system. A temperature sensor located in the return air duct of the HVAC system is connected to the thermostat which regulates the room temperature by turning off or on compressors as required. The room temperature and fan controls are adjusted via thermostat. Moreover, thermostat can display different error codes for problems such as ahu coil sensor failure, insufficient or loss of refrigerant, compressor overload, low or high refrigerant pressure, ahu coil freezing etc. Whenever an HVAC unit trips abnormally the corresponding error code is displayed on the thermostat box which helps the technical staff in diagnosing the problem immediately and accurately.

RCM INFORMATION WORKSHEET

RCM information worksheet is developed to define function of major components of HVAC system. The individual functions of AHU, CUN, Thermostat box is defined along with their functional failure which describes the loss of function. Some major failure modes of each component are discussed along with their failure effect on the operation of the Laboratory. RCM information work sheet is shown in Table 1:

Table -1 RCM Information Worksheet

RCM II Information Worksheet		**System: AHU based DX Unit DX-AHU112 (SWSI)-HBT-BI-DS + CU080D**					
		Sub-systems:		**1) Air handling Unit**		**2) Condensing Unit**	**3) Thermostat box**
Function		**Functional Failure**		**Failure Mode**		**Failure Effect**	
1	It is responsible for filtering, cooling and pumping air throughout the central ducting system	A	The AHU will stop supplying conditioned air to the respective zone	1	Broken fan belt	There will be a loss of temperature, humidity & differential pressure resulting in unavailability of lab. If there is any process going on which requires conditioned environment it will be stopped which will result in financial loss and unexpected downtimes.	
				2	Leakage in Evaporator coil		
				3	Motor is burnt		
2	It is responsible for rejecting heat into the surrounding air, and supplying cool refrigerant to the AHU for heat exchange	A	Heat rejection in the environment will stop and vapor compression cycle will stop working	1	Compressor failure	There will be a loss of cooling and dehumidification in the area. Temperature & humidity will not be maintained; hence lab will become unavailable	
				2	Coil Leakage		
				3	Fan motor failure		
3	Thermostat box	A	Loss of control for AHU and condensing unit	1	Circuit failure	The entire HVAC system will stop working resulting in unavailability of Laboratory.	

RCM DECISION WORKSHEET

The methodology for RCM decision worksheet has been obtained from "Reliability Centered Maintenance by John Moubray". The terminologies used in the sheet are described as: 1.) F: Function 2.) FF: Functional Failure 3.) FM: Failure Mode. The remaining methodologies and method can be found in John Moubray book, page 200-201.The RCM decision worksheet is shown in Table-2:

Table -2 RCM Decision Worksheet

RCM II decision worksheet			**Unit**				**AHU Based HVAC System**						
Component:			**1) Air Handling Unit**							**2) Condensing unit**			**3) Thermostat Box**
Information reference			**Consequence evaluation**				**H 1**	**H 2**	**H3**	**Default Action**			**Proposed Task**
							S1	**S2**	**S3**				
							O 1	**O 2**	**O3**				
F	**F F**	**FM**	**H**	**S**	**E**	**O**	**N1**	**N 2**	**N3**	**H 4**	**H 5**	**S4**	
1	A	1	Y	N	N	Y	N	N	Y				Schedule discard task
1	A	2	N				N	Y					Schedule restoration task
1	A	3	Y	N	N	Y	N	Y					Schedule restoration task
2	A	1	N				N	N	Y				Schedule discard task
2	A	2	N				N	Y					Schedule restoration task
2	A	3	Y	N	N	Y	N	Y					Schedule restoration task
3	A	1	Y	N	N	Y	N	N	Y				Schedule discard task

PROPOSED MAINTENANCE STRATEGY

In order to keep the HVAC system in working condition and assure 24/7 lab availability it is important to follow a preventative maintenance schedule as discussed in Table-3:

Table -3Proposed Maintenance Strategy

Components	Maintenance Procedure	Recommended Schedule
Air Filters	1. Clean the filters with a vacuum cleaner, tap the filter on a soft surface then rinse the filter with a detergent and warm water. 2. Rinse well & dry the filters before reinstallation in Air handling Unit.	At least after every 15 days, if environment is dusty do it more frequently
Bag Filters	1. Measure the differential pressure across bag filters, if pressure exceeds 1.2" WC, replace the filters immediately.	Check every two months, if environment is dusty check every month.
Evaporator & Condenser Coils	1. Use a high-pressure washer to clean and remove any dirt that is clogging the coils	Every two months, more frequently if environment is dusty.
Condensate drain pan & pipe	1. Check for any blockage and clean the drain pan	After every 3 months
Condenser Fans	1. Check for any unusual vibration and noise 2. Check that fan rotation is correct 3. Check that all rigid mountings are in place	Every 2 months, or as required if any problem is detected.
Evaporator fan	1. Check for any unusual vibration and noise 2. Check that fan rotation is correct 3. Check for belt tension and pulley alignment 4. Check & replace damaged belts	Every 2 months, or as required if any problem is detected.
Fan motors lubrication	1. Motors are lubricated and sealed at factory	No maintenance is necessary unless the motor is opened
Electrical	1. Monitor Voltage, current, & wiring 2. Check for loose connections and worn out contacts 3. Make sure all connections are tightened	After every 2 months
Compressor lubrication	1. If there is a leak in the refrigerant piping, check oil level otherwise it is not necessary	Check if piping has leaked
Refrigerant piping	1. Check leakages at joints and fittings	Check after every 6 months

After an extended shutdown make sure to follow the steps described below:

1. Make sure all above maintenance procedures are performed.
2. Make sure the evaporator and condenser fan rotation is in the correct direction.
3. The compressor's crankcase heater should be turned on 24 hours before starting the HVAC system, however in case of scroll compressors there are no crankcase heater.
4. Check system pressure and make sure there are no leaks in the refrigerant circuit.

RCM COST ESTIMATION AND CONSEQUENCES

As per original equipment manufacturer (Sabro) the cost of common spare part of an AHU based HVAC system [AHU based DX Unit DX-AHU112 (SWSI)-HBT-BI-DS + CU080D] is as shown in Table-4:

Table -4RCM Cost Estimation

S.No	Unit Description	Unit Price (PKR)	Quantity	Total Amount (PKR)
1	Contactor for Compressor	4,500	2	9,000
2	Contactor for Condenser Motor	4,500	1	4,500
3	Contactor for Evaporator Motor	4,500	1	4,500
4	Overload for Compressor	4,500	2	9,000

5	Overload for Condenser Motor	4,500	1	4,500
6	Overload for Evaporator Motor	4,500	1	4,500
7	Power Monitor	12,000	1	12,000
8	Fuse	50	2	100
9	Thermostat	35,000	1	35,000
10	Aluminum Filters	3,500	1 set	3,500
11	Filter Drier	3,000	2	6,000
12	High Pressure Control	6,000	2	12,000
13	Low Pressure Control	6,000	2	12,000
			Total amount	**116,600**

Currently there is no preventative measurement schedule being followed at forensic lab, the entire facility is on Run to Failure Maintenance which means when a particular equipment breaks down, technicians are called to resolve the issue. This incurs higher cost and unavailability of Lab during breakdown which causes unexpected delays in the decision of court cases. However, if the proposed maintenance strategy which is discussed previously is followed than we can ensure 24/7 lab availability and save cost from following scenarios:

1. Chocked filters and clogged coils can reduce efficiency of HVAC system with respect to pumping and efficient heat transfer of return air. The chocked filters increases static pressure drop in the air handling unit which causes increases the motor current to the point that air flow starts to decrease in the central ducting system and a loss of cooling/heating occurs. Similarly, when a coil is clogged heat transfer is reduced and the air is not cooled/heated up to the designed specifications. The combined effect of chocked filters and clogged filters can reduce overall system efficiency by 13-15% [14]and increase electricity bills correspondingly. This case study was carried out by Goodway technologies corporation which provides cleaning solution for HVAC systems.
2. If coils are not washed periodically, the dust clogging the coils combines with the moisture in the air and start the pitting process until the refrigerant circuit leaks, if the refrigerant circuit leaks than repairing it will incur the cost as indicated in Table-5.

Table -5 Repairing Cost

Name	Quantity	Unit Rate (PKR)	Total Rate(PKR)
Labor cost	3 days	2,500	7,500
Welding equipment and copper rod	1 lot	6,000	6,000
Nitrogen Cylinder	3 Nos.	1,200	3,600
Honeywell R-407c refrigerant cylinder	2.5 Nos.	20,000	50,000
		Total amount	67,100

Similarly, if the electrical box in the condensing unit is not cleaned after recommended intervals it will eventually result in contactors, power monitors getting faulty due to dust and high humidity. The cost of replacement has been discussed previously. In the light of above discussion, it is clear that just from proper maintenance thousands of rupees can be saved per HVAC system. Hence it is important to follow a preventative maintenance procedure in order to save cost and ensure lab availability.

CONCLUSION

An airhandling unit based hvac system is a complex machine that requires periodic maintenance of its component to ensure smooth function. A complete preventative maintenance procedure has been developed and discussed in detail in the previous section. If the proposed maintenance procedure is followed, we can avoid breakdown maintenance and prolong the equipment's life. Moreover, the lab unavailability which is cannot be accepted is also avoided if all the units are maintained as per OEM's requirement. Hence it is imperative for the government to hire trained staff or outsource maintenance contract to certified maintenance teams who can keep the equipment in mint condition.

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