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IMPACT OF A PREVENTIVE MAINTENANCE PROGRAM FOR HVAC SYSTEMS IN HOSPITALS: A CASE STUDY OF KITWE CENTRAL HOSPITAL

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Abstract - The purpose of the research was to assess the benefits that come with implementing a preventive maintenance system in the hospital heating, ventilation and air-conditioning (HVAC) systems. The run-to-failure maintenance strategy of the HVAC system practiced at Kitwe central hospital affected the quality of health operations considering the increase in demand due to population growth. The researchers set objectives focusing on minimizing downtime to sustain the reliability of the equipment, lowering utility costs and greatening comfort for the building's occupants. Initially, the types of HVAC equipment at the hospital were identified and an inventory list was developed. The Mean Time Between Failures (MTBF) of the equipment was then established together with the lead times of the inventory items. Finally, the design of a replacement program based on the gathered data was developed. With the implementation of the preventive maintenance program, the benefits of the research came doubled folded; the reliability of the HVAC equipment increased and high utility costs which were incurred due to the frequent breakdowns and poor utilization of machines and employees reduced significantly. The researchers recommend the preventive maintenance for the HVAC system not only to Kitwe hospital but to other hospital for operations enhancement in promotion of good health.

Index Terms-Hospital, HVAC System, Preventive Maintenance, Run-to-failure

1 INTRODUCTION

The primary requirement of the heating, ventilating and air conditioning (HVAC) systems in a medical facility is the support of medical function and the assurance of occupant health, comfort, and safety. The HVAC system functions not only to maintain minimum requirements of comfort and ventilation, but is an essential tool for the control of infection, removal of noxious odors, dilution and expelling of contaminants, and establishment of special environmental conditions conducive to medical procedures and patient healing (P.Guyer, 2009).

This research paper therefore focused on promoting good health in a hospital by implementing a preventive maintenance program on heating, ventilation and air-conditioning systems. The research was based on a case study of Kitwe Central hospital which is a public hospital. The hospital heating, ventilation and air-conditioning systems were identified and then an inventory of the systems was developed. The major HVAC equipment at Kitwe Central Hospital are; the boiler, cold room units, extraction fans, dehumidifiers and domestic fans. Maintenance of equipment at Kitwe Central Hospital is operated on a run to failure strategy (breakdown maintenance).

The hospital operates the equipment on a daily basis and repairs are done when a component or equipment breakdowns. Workers in the maintenance department not only source the part to use in the repair of the equipment after it has broken down, which results in a long equipment downtime but also there are challenges of administrative delay and logistic delay times. Implementing a Time-based maintenance strategy (preventive maintenance) in a hospital will favor its operations considering that these equipment are directly involved in the provision of good health.

Preventive maintenance programs for air conditioning and heating equipment include regular inspections each year. During these inspections, proper operation of the equipment is checked and verified. All mechanical equipment is designed to operate within certain limits. Air conditioning and heating equipment is no exception, and if not properly maintained, the equipment will exceed its

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design limitations with the result being equipment failure. Your best insurance against HVAC failure and cost containment is equipment preventive maintenance (James Piper, 2009).

The problem of implementing a system for maintaining heating, ventilation and air-conditioning (HVAC) systems in hospitals is not a new one. Several approaches have already been tried by various institutions in trying to reduce the downtimes due to breakdowns of these equipment. In spite of years of studies, demonstration programs, and published stories to the contrary, most facility organizations today still operate in a reactive mode. Though facility executives know that is far better to schedule maintenance activities using planned and predictive maintenance tools, most continue to spend the bulk of their resources operating reactively. The most common reasons cited for this is the lack of sufficient resources (James Piper, 2009).

The approach to maintenance with respect to HVAC systems in this research was based on designing a preventive maintenance program for the maintenance department focusing on the critical HVAC equipment for Kitwe central hospital. An inventory of HVAC critical equipment for the hospital was established and then a detailed listing of the equipment parts with assigned codes for each part for ease of identification followed. Development of job details for each part then followed focusing on replacement job details and sourcing lead times for all the critical equipment parts. A schedule as in how preventive maintenance will be conducted was then drawn.

2 METHODOLOGY

To achieve success in this research, it was imperative that information was obtained from reliable sources. Strategies on how to obtain this information included the following:

2.1 Primary Data

Initial familiarization with the heating, ventilation and air-conditioning systems at the hospital was carried out while taking special note of the following points:

- Methods and systems of maintenance used.
- Manpower
- Time available for maintenance.
- Shift- work system.
- The actual equipment involved.

2.2 Initial familiarization survey of the maintenance department

This was done taking note of the following:

- Resources and limitations
- Manpower type and number of tradesmen.
- Machines and equipment available.

2.3 Interviews

The interviews were conducted with the engineering maintenance supervisor considering the small number of employees in the department. These interviews were conducted to find out the following concerning the HVAC equipment/machines that the hospital has:

- The number of major pieces of equipment and machines that the hospital has and their applications.
- The components which frequently breakdown on each piece of equipment.
- Mean time to failure (MTTF) of each of the equipment.
- The sourcing lead-time of each of each component
- The quantity of each type of component present on a piece of equipment.
- The mode of failure of each component of the equipment.
- The time it takes to replace the component on the equipment
- The trade of the person to carry out the task, whether electrician or fitter etc.

2.4 Direct Observations

This assisted in obtaining information about the physical activities and taking note of the events as they occurred.

2.5 Secondary Data

The other relevant information concerning heating, ventilation and air-conditioning systems and preventive maintenance was obtained from the records kept at the hospitals' maintenance department, which concerns the number of equipment the hospital has (asset register), the number of breakdowns of each piece of equipment considering the critical components that fail.

3 RESULTS

The HVAC system at Kitwe Central Hospital consists of sizable number of equipment that work together to provide the hospital heating, ventilation and air-conditioning requirements.

3.1 Hospital's HVAC System Inventory

The asset inventory equipment is as shown in Table1 below.

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TABLE 1.HVAC SYSTEM INVENTORY

Ref	Item	Quantity	Application
1	Electrical Boiler	1	Heating rooms, kitchen, laundry and the theatre
2	Cold Room unit	3	Storage of corpses
3	Exaction Fan	19	Extraction of air from rooms, theatre and other departments
4	Domestic Fan	20	Air-conditioning rooms, wards and offices.

3.2 Parts' Listing

Each piece of the equipment listed in Table1 is made up of various components or parts. Different parts serve different functions within each unit of equipment and they have different modes of failures as well as operating live (i.e. mean time to failure).

3.3 Focus on Critical Parts

The failure of some components may be more critical to the overall performance of the hospital's HVAC system than that of others. This research focused only on those parts deemed to be critical to the optimal functioning of the hospital's HVAC system. The preventive maintenance program is drawn up only for these parts.

3.4 Parts' coding nomenclature

A detailed listing of the parts followed, with assigned codes for ease of identification of the components.

The code is based on the following:

- It is made up of six characters that distinguish each unique part.
- The first two characters are for family identification, indicating on which piece of equipment the part is used.
- EB- Electrical Boiler
- EF- Extraction Fan
- AC- Air-Conditioner
- CR-Cold Room unit
- DF- Domestic Fan
- The next two characters are numbers from 01 to 09 assigned within each family, e.g. EB01 to EB09, DF01 to DF09 etc.
- The fifth character is a letter representing the functioning of the part as follows;
- M- Mechanical
- E- Electrical
- T- Other part
- The sixth and final character is a letter indicting the physical nature of the part as follows;
- M- Metal
- R- Rubber
- P- Plastic
- O- Other

3.5 Parts' List by Equipment

TABLE2. LIST OF PARTS OF EQUIPMENT

ITEM	PART NUMBER	DESCRIPTION	QUANTITY/UNIT	TOTAL PARTS	MTTF(WEEKS)	FAILURE MODE
ELECTRICAL BOILER	EB01EM	Mild steel electrode	3	3	26	Scaling
	EB02MM	Sleeves	9	9	52	Loss of insulation due to heat
	EB03ER	Blow down hose	2	2	104	Crack or puncture
	EB04EM	Control transformer	1	1	104	Insulation resistance
COLD ROOM	CR01EM	Compressor motor 2HP, 380	1	3	74	Burnt winding or ceased motor
	CR02MM	Compressor piston	2	6	156	Swaps/breaks due to lack of lubrication
	CR03MM	Compressor shaft	1	3	156	Breaks due to tear and wear
	CR04MR	Compressor seal	2	6	104	Wears out
	CRO5M0	Compressor gasket	1	3	74	Burns out due to excessive heat
	CR06MM	Compressor valve	2	6	104	Wears out
	CR07EO	contractor valve 220VAC, 30V	2	6	116	Fails to change
	CR08EM	Contractor fan motor 0.5kw	1	3	52	Motor burn out or cease due to bearing
	CR09MM	Condenser copper line embedded fins	1	3	156	Wear and tear, corrosion
	CR10TO	Refrigerant R134A	1	3	156	Leak out from seals
	CR11EM	Evaporator motor 1kw 38VAC	2	6	74	
	CR12MT	Expansion valve 2"	1	3	156	Fails to hold(due to dirty orifice)
EXRACTION FAN	EF01EM	Electric motor 0.55kw	1	19	104	Motor burn out
	EF02EM	Ball bearing	2	38	39	Ceases due to heat up or dryness
	EF03MP	Blade	1	19	52	wear and tear
DOMESTIC FAN	DF01EM	Electric motor 0.01kw	1	19	52	motor burn out
	DF02MM	Sleeve	2	38	28	wears out due to lack of lubrication

3.6 Job Details

Table3 shows for each item, the specific details of the replacement job and the sourcing lead times involved.

TABLE3. REPLACEMENT JOB AND JOB DETAIL AND LEAD TIMES

ITEM	NO. OF ITEMS IN SYSTEM	COMPONENTS	TIME TO REPLACE (HRS.)	TOTAL HRS REQUIRED TO REPLACE PART ON ALL UNITS	EQUIV. DAYS FOR AVAILABLE LABOUR	TIME TO SOURCE (WKS)	TASK TO BE DONE BY
ELECTRICAL BOILER	1	EB01EM	8	8	1	8	Electrician
	1	EB02MM	2	2	1	8	Fitter
	1	EB03ER	1	1	1	1	Fitter
	1	EB04EM	8	8	1	1	Electrician
COLD ROOM	3	CR01EM	8	24	3	4	electrician
	3	CR02MM	2	6	1	2	Fitter
	3	CR03MM	1	3	1	1	fitter
	3	CR04MR	1	3	1	1	fitter
	3	CRO5M0	1	3	1	1	fitter
	3	CR06MM	1	3	1	4	fitter
	3	CR07EO	2	6	1	1	fitter
	3	CR08EM	4	12	1	1	electrician
	3	CR09MM	3	9	2	3	electrician
	3	CR10TO	1	3	1	2	fitter
	3	CR11EM	6	18	2	1	electrician
	3	CR12MT	1	3	1	1	fitter
EXRACTION FAN	19	EF01EM	1	19	3	4	fitter
	19	EF02EM	2	38	5	1	fitter
	19	EF03MP	1	19	3	4	fitter
DOMESTIC FAN	20	DF01EM	4	80	5	3	electrician
	20	DF02MM	1	20	3	1	fitter

Assumptions:

- Each technician works 8 hours/day, 5 days/ week
- There are 2 electrical artisans and one mechanical artisan available for jobs
- A job that will take 8 hours to complete and a task that will take only 3 will both be considered as requiring one day.

The preventive maintenance schedule for the electric boiler is given in Table4.

3.7 Utility Costs Reduction

3.7.1 Energy Savings

It was estimated that the annual power bill for Kitwe central hospital is K 14,000,000. It was established that electrical motors (biggest load) at the hospital account for 80% of the total power bill. Furthermore, these motors are operating at 90% of their full load-load ratings. With the implementation of a preventive maintenance program, this would reduce to approximately 75% full load current due to reduced energy consumption after replacement of such parts as bearings.

3.7.1.1 Illustration of the Energy Savings

Annual power bill is K14000, 000
Cost attributable to electric motors
80% X K14000, 000 = K11, 200,000
This is at 90% power rating.
Power Bill with Preventive Maintenance
At 75% of rating cost would be:
75% X K 11200000/90% = K 9333333
Calculation of Energy Saving
K11, 200000 – K 9333000 = K 1, 866,667
Percentage of Energy Saving
1866667/11200000 = 17%
Implementing Preventive Maintenance would result in energy savings of 17%.

TABLE4. ELECTRICAL BOILER PM SCHEDULE

MONTH	WEEK	INITIATE SOURCING	ARRIVAL OF PART	TOTAL TIME TO REPLACE	DOWN FOR MAINTENANCE	TASK TO BE DONE BY	PREDETERMINED BREAKDOWN
Apr	16	electrode x 3 EB01EM					
Dec	24		electrode x 3 EB01EM				
				6	electrode x 3 EB01EM Replace Electrodes	electrician	
Feb	26						EB01EM x 3
Jun	42	EB02MMx 9					
Feb	50		EB02MMx 9				
Mar	51			18	EB02MMx 9 SLEEVES	Fitter x 1	
Apr	52						EB02MMx 9
Mar	101	EB03MRx 2 blow down hose					
Apr	102		EB03MRx 2				
May	103			2	EB03MR x 2 replacement	fitter x 1	
Jun	104						EB03MR x 2

3.7.2 Labor Savings

Considering using preventive maintenance program, the hospital would consider subcontracting the workforce to work on the critical components. This would lead to a considerable amount of savings in labor. In contrast, if no preventive maintenance program is in place, and then labor will always have to be there because no one will know when a breakdown will occur.
The savings in labor between the two systems of maintenance are now compared.

3.7.2.1 Labor costs with Breakdown Maintenance

First the labor cost over a three-year period is calculated. The length of the period is three years because it has to concur with the Preventive maintenance schedule's cycle.
156 weeks is equivalent to 780 days (if 1 week = 5 days)
Each worker works for 8 hours/day
Each worker is paid K 3700/hour
Each foreman is paid K4500/hour
There are four (4) workers
There are two (2) foremen.
For 780 days, which is a period of 3 years, cost will be:
780 X [(4X 3700X 8) + (2 X 4500 X 8)] = K 148, 512, 000

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It is assumed that the entire work-force is not absent on any day

3.7.2.2 Labor Costs with Preventive Maintenance

Considering the number of hours when replacement of the critical components is needed in the three- year period, and if the hospital decides to subcontract the workforce.
The total work hours required will be 113
Assuming a contractor's workforce of 1 foreman and three artisans, the hourly cost is
3 X K 3700 + K4500 = K 15, 600
Therefore, total cost for 113 hours
113 X K 15600 = K 1, 762, 800
If we further assume that the contractor puts a mark-up of 30% on all labor charges, then
Total cost = 130% X K 1 762 800
K 2, 291, 640
Labor Savings
The labor savings are;
K 148, 512, 000 – K 2, 291, 640
K 146,220,360

3.8 Greater comfort for the building's occupants.

Though it may be difficult to quantify this in figures, this was proved by interviewing the hospital occupants especially the nurses and workers of the hospital by asking the important questions such as:
How working in a room that is not well ventilated and air-conditioned affects their moral at work?
The challenges faced when cold-rooms breakdown.
The risk of infection if there rooms are not well ventilated
The answers to these questions where all directed towards having a system in place that will prevent HVAC systems breakdown and therefore improving system availability.

4 Discussions

HVAC systems are critical in creating a comfortable indoor environment and reducing the incidence of hospital acquired infections. Ventilation needs to meet the specific requirements of hospital units, patient rooms and common areas. Proper ventilation is critical since one-third of all infection threats are airborne. Temperature affects patient, staff and visitor comfort. Maintaining the right temperature can also help create an indoor environment that promotes healing and makes it harder for pathogens to grow and spread. To achieve this in HVAC systems, there is need for a maintenance program or schedule which can be used by the hospital and in this research, preventive maintenance was the best strategy as it prevents breakdowns from occurring and thus reducing the downtime period for the equipment. In the case of greatening the comfort of hospital occupants, if there is a schedule for cleaning these critical equipments, it will harder for pathogens to grow and spread in an environment that is kept clean.

In the schedule designed for Kitwe central hospital, critical parts for the HVAC equipments were considered to enable the program practical and easy for the department to use and implement. This schedule or program was designed considering that the cost of implementing a preventive program is costly and thus the research focused only on these equipments which were deemed critical to the operation of the hospital. From the data that was obtained from the interviews and familiarization with the HVAC systems and maintenance department, it was possible to design a simple but yet practical preventive maintenance program for this hospital. Focusing on the utility cost reduction, it was possible to reduce the cost of energy if critical components such as motors are operating efficiently and in good condition.
Instead of waiting for problems to arise, hospitals can take a proactive approach to air conditioner maintenance and reduce energy costs. Scheduled HVAC maintenance reduces the possibility of service disruption, indoor air contamination and costly repairs. Considering the fact the critical components for the hospital HVAC system are known and their operating lives though not very exact and the lead times for these components been known together with the maintenance personnel to repair and also the knowledge of the failure history available, it becomes possible to build these in the maintenance department operating costs, regular HVAC service can become a manageable fixed cost, necessary to keep the facility running efficiently and therefor reduce the costs as a result of breakdown maintenance as demonstrated in the results section.
HVAC systems that are not performing at peak efficiency can seriously affect a hospital's environment of care by allowing indoor air quality to deteriorate. For example, a faulty dehumidification system could create a humid environment where problems and pathogens can grow and therefor cause and increase the spread of infections. Conducting an HVAC critical system audit, can help hospital facilities managers identify potential reliability and performance problems, reduce the chance of unplanned system failure and identify energy saving opportunities (Medical Construction & Design, 2011)
The system designed for Kitwe central hospital focused only on the critical equipments and also it was more of a manual program which can be improved upon by programming the system and adding more HVAC equipments as the hospital is expanding.

5 Conclusion

The designed preventive maintenance program is a good start for a hospital that does not have the money to invest in a computerized system. This program may take some time but it is a cheap way to start implementing preventive maintenance to HVAC systems. Implementing preventive maintenance will certainly improve the comfort of the buildings' occupants accompanied by an increase in the availability of the equipment to perform its operation.

6 RECOMMENDATIONS

The researcher recommends that the system be converted to a computerized version that can be able to incorporate more HVAC equipment for the hospital. The maintenance staffs need regular refresher training in order to be in full control of the system.

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