DEVELOPING A MAINTENANCE STRATEGY PLAN TO IMPROVE ENERGY EFFICIENCY OF HVAC SYSTEM

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ABSTRACT

In managing energy in buildings, a greater focus has been given to the HVAC system as it generally consumes more than 50% of total energy usage in buildings. Proper maintenance had been identified as a significant factor to improve energy efficiency of HVAC systems. For instance a proper maintenance plan can save 5% - 20% of energy bills without a significant capital investment. Thus, the research aims to develop a maintenance strategic plan to improve energy efficiency of HVAC systems. Survey technique was adapted to collect data on HVAC system failures, impact of failures, frequency of each failure, significance of causes for failures and HVAC Maintenance requirements to ensure efficiency. A statistical analysis was carried out to develop a maintenance strategy plan. Maintenance strategic plan is proposed by using the preventive and predictive maintenance strategy. This proposed plan may be useful for building managers to manage energy by adopting efficient maintenance strategies.

Keywords: *Energy Efficiency; HVAC System; Maintenance; Predictive Maintenance; Preventive Maintenance.*

1. BACKGROUND

HVAC stands for heating, ventilation and air conditioning and refers to the equipment, distribution network and terminals used either collectively or individually to provide fresh filtered air, heating, cooling and humidity control in a building (ASHRAE, 2009). Moreover, Zhang (2005) has mentioned that the HVAC Systems are mechanical systems providing artificial environment for either operational requirement or health and comfort of the occupants. According to Johnson (1995) the main goals of HVAC system is to maintain the comfort and health of occupants or the supplying of a set of environmental conditions for a process or product in a conditioned space.

The choice of HVAC system depends on initial cost, energy cost, maintenance effort and cost, coordination with other trades, spatial requirement, acoustics, flexibility, architectural aesthetics, and many other issues (California energy commission, 2005). HVAC system is the largest energy consumer in a building thus potentially an area where large energy savings may be realized. According to Liddament and Orme (1998), HVAC system approximately consumes more than 50% of energy from the total building energy usage (Figure 1).

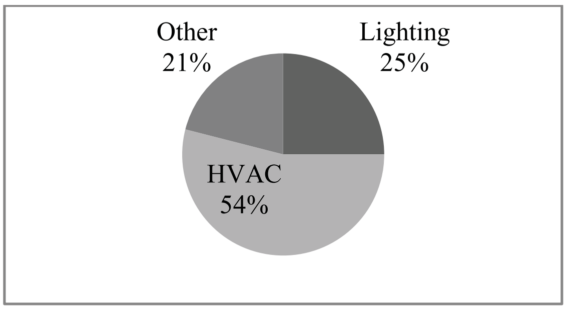

Figure 1: Breakdown of the Total Building Electrical Energy Consumption (Source: Liddament and Orme, 1998)

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US Department of Energy (2010) has been estimated that operation and maintenance programs targeting energy efficiency can save 5% to 20% on energy bills without a significant capital investment. Moreover, office of the legislative auditor (2010) has mentioned that training maintenance workers in preventive maintenance, improved the efficiency of HVAC operations saves an estimated 6% to 19% of their total annual energy bills. Adequate cleaning of the condenser or evaporator coils could provide the same amount of cooling with 30% to 40% percent less energy consumption than inadequate cleaning (Office of the legislative auditor, 2010). According to western area power administration (2006) an improperly maintained cooling tower will produce warmer cooling water, resulting in a condenser temperature 5 to 10 degrees F higher than a properly maintained cooling tower. This reduces the efficiency of the chiller, wastes energy, and increases cost. The chiller will consume 2.5 to 3.5 percent more energy for each degree increase in the condenser temperature. Proper maintenance is necessary to achieve optimal energy performance, while energy performance data is needed for effective maintenance management. When the tensions between energy performance and maintenance practices are balanced, buildings operate efficiently as shown in the Figure 2.

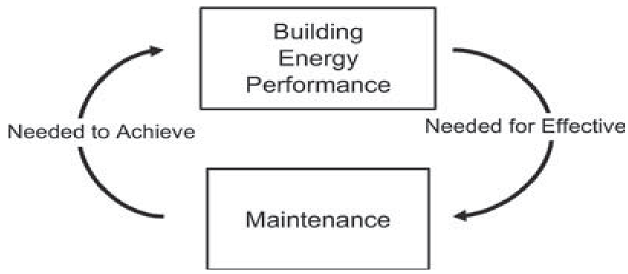


Figure 2: Link between Energy Performance and Maintenance
Source: (Lewis and Elmualim, 2010)

Western area power administration (2012) identified most common failures of HVAC system which affects the functionality such as leak of refrigerant, compressor failures, fan motor failures, electrical failures, fan bets failure, scale deposit, valve failure, drain pump leak and pump failure. Chandrashekaran and Gopalakrishnam (1999 cited Abramson and Magee 2008) has explained that preventive maintenance and predictive maintenance can be used to improve HVAC failure checkpoints, such as scale, corrosion, fouling of heat transfer surfaces, misalignment, improper lubrication, lack of calibration in control systems, equipment operating unnecessarily, excessive parasitic losses, leaks, and failure to utilize free energy sources. According to Chandrashekaran and Gopalakrishnam by using this can be achieved 6 % -19 % potential energy savings in HVAC system. Cleaning, replacing damaged items, visual inspection, chemical treatment and checking water in/ out temperature are some of the preventive maintenance and predictive maintenance activities which need to be carried out in regular basis (Schoen, 2003).

Robert and Rosaler (1997), Lofsten (1999), Deshmukh and Garg (2006) and Luxhoj *et al*. (1997) mentioned that preventive maintenance is time based maintenance which a series of tasks performed at a frequency dictated by the passage of time. Predictive maintenance is the extrapolation of graphic trends of measured physical readings against known engineering limits for the purpose of detecting, analyzing, and correcting equipment problems before failure (Raouf and Ben-Daya, 1995; Tsang, 2002). Jabar and Perkasa (2003) have mentioned that the proactive maintenance strategy is also designed to extend the useful age of the equipment to reach the wear-out stage by adaptation a high mastery level of operating precision. According to Horner (1997 cited David and Arthur 1989) has mention that corrective maintenance tasks often take places in an *ad hoc* manner in response to breakdowns or user requests. It is required to use a combination of all these maintenance strategies to obtain the optimal performance of a system.

2. RESEARCH METHODOLOGY

Surveys are normally used where the views or opinions of many need to be evaluated in order to achieve a conclusion. Therefore, survey research has been selected as the most suitable research approach. A literature survey was undertaken, in order to identify practising maintenance strategies, the failures arise in the HVAC system and the maintenance activities could be carried out to avoid these failures. These finding were further validated using a pilot survey where an expert was involved. In order to collect the data from the industry a structured questionnaire survey was developed using the identified practising maintenance strategies, HVAC failures and maintenance activities. A statistical analysis was carried out to analyse collected data; mainly t-test was carried out using SPSS software with 95% confidence interval. Preventive and predictive maintenance activities were proposed for chiller maintenance based on the literature survey.

3. RESEARCH FINDINGS

3.1. PRACTICING MAINTENANCE STRATEGIES

Survey results showed that *preventive maintenance* strategy was the most widely practicing method in most of the organizations. Furthermore, combination maintenance strategies are also popular among organizations which information is presented in Figure 3.

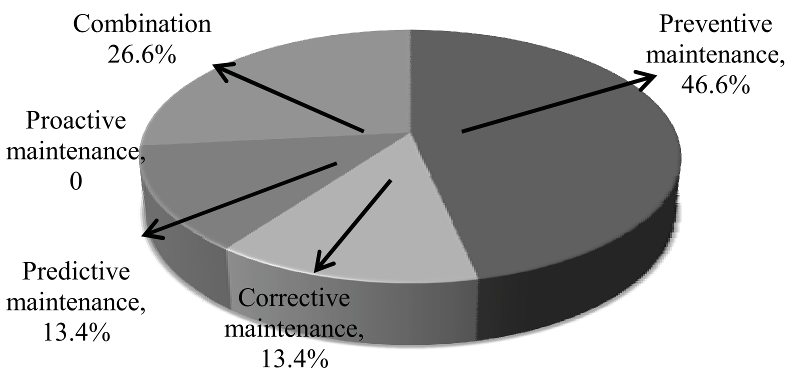


Figure 3: Usage of Maintenance Strategies

3.2. HVAC MAINTENANCE REQUIREMENTS

Maintenance requirements for HVAC system were analyzed according to the three common systems available as, Central A/C system, Split type A/C and package A/C. The following section discusses their maintenance requirements in detailed.

3.2.1. CENTRAL A/C SYSTEM MAINTENANCE

Maintenance requirements for Central A/C system were analysed according to the three main components including (1) chiller, (2) cooling tower and (3) pumps. Maintenance activities for each component were proposed and practitioners were asked to mark the importance of each proposed maintenance activity on a given scale of one to five representing very high, high, medium, low and very low respectively. T-value and significance of each maintenance activity was calculated and ranked them based on the t-values to identify most important maintenance activities. The following section discusses their maintenance requirements in detail.

Chiller

Table 3: Maintenance Requirements for Chiller

Factors		95% Confidence Interval of the Difference			
		t- Value	P Value	Mean Rating	R
1	Inspect for water leaks	-5.635	.000	-.933	1
2	Checking all oil levels and pressures	-6.528	.000	-1.100	2
3	Check Chilled water in/ out temperature	-3.516	.001	-.767	3
4	Checking all electrical starters, contactors and relays	-3.515	.001	-.733	4
5	Inspect purge unit operation	-3.440	.002	-.667	5
6	Check for unusual noise and vibration	-3.194	.003	-.733	6
7	Prompt power consumption	-2.850	.008	-.633	7
8	Assess proper water flow in evaporator and condenser	-2.628	.014	-.500	8
9	Check for chill fouling in Chilled water/ Condenser Water	-2.523	.017	-.600	9
10	Conduct leak testing on all compressor fittings, oil pump joints and fittings , and relief valves	-2.408	.023	-.500	10
11	Prompt cooling capacity	-2.347	.026	-.500	11
12	Checking compressor operating pressures	-2.333	.027	-.533	12
13	Check Condenser Water in/ out temperature	-2.186	.037	-.500	13
14	Inspect water treatment process	-2.151	.040	-.533	14
15	Check Ph of condenser water	-1.000	.326	-.207	15
16	Check Ph of chilled water	-.817	.420	-.167	16
17	Eddy current testing for chiller tubes	-.701	.489	-.133	17

T-test analysis showed that fourteen maintenance activities have a p-value less than 0.05 and others have p-values more than 0.05 (Table 3). Therefore, activities which have p-value less than 0.05 can be considered as most significant activities which need to be carryout in a regular basis. It is important to inspect the water leaks of the chiller shell and tube heat exchanger. The tube can fail due to corrosion and the resulting leak would be catastrophic, resulting in rapid failure and expensive repair and replacement. To predict and prevent such failure, eddy current analysis is used to detect the condition of the heat exchanger surface.

The failure of an oil pump is another critical faulty in HVAC system. All compressors which are used oil pumps should have an oil failure control system and proper working order. The condensing pressure is the amount of pressure required within the system to take the heat out of the water. The condensing pressure can be measured with the set of pressure gauges on the pressure taps at the inlet and outlets of the condenser itself. If the two are more than three degrees different, need to check the purge system operation for leaks. Maintain the makeup water supply pressure between 15psig and 50 psig to ensure proper valve shut off and to avoid failures. If the supply pressure is higher than 50 psig, install a pressure reducing valve. The function of any float valve is allow a reasonable discharge into a cistern and be capable of closing off against maximum pipeline pressure. Frequent reasons for failures in float valve are Dirt on valve seat, Valve face is worn, the float / lever mechanism has insufficient operating force to close against the shut off pressure. In order to avoid these failures must do the clean and replacement accurately.

Difference between chill water in out temperature should be maintained at the acceptable level. If not it will cause inefficiency in both chiller and the cooling tower. Temperature sensors and motorised valves should be placed appropriately to avoid unnecessary cooling by the chiller. Maintaining all electrical starters, contactors and relays is essential to enhance the automatic operation of the equipment. If not equipment may operate without any usage which will cause energy inefficiency.

Cooling Tower

According to t-test, there were six important maintenance activities for cooling tower maintenance. Among the proposed fourteen activities, eight are not consider as important and not significantly practice in the industry. Table 4 shows more details on calculations and ranking of each activity.

Table 4: Maintenance Requirements for Cooling Tower

Factors		95% Confidence Interval of the Difference			
		T-Value	Sig:	Mean Rating	Rank
1	Cooling tower entering/leaving temperature	-3.45	.002	-.793	1
2	Check the condition and lubricant the bearing, replace if necessary	-3.46	.002	-.690	2
3	Use high pressure water pump and clean entire CT, start from top to bottom	-3.01	.005	-.552	3
4	Fouling - check for algae build up	-2.73	.011	-.483	4
5	Check the condition of the fan motor through temperature or vibration analysis and compare to baseline values	-2.65	.013	-.552	5
6	Cooling tower fan motor current (Amp)	-2.24	.033	-.517	6
7	Sump free of debris / no algae	-2.04	.051	-.448	7
8	Check for excessive vibration in motors, fans, and pumps	-1.84	.076	-.414	8
9	Check motor terminal and tight them	-1.75	.091	-.448	9
10	Check V-belts and pullies of the motor and align them properly	-1.39	.174	-.310	10
11	Open CT in and out valves, put on condenser pumps and CT fan and balance the system	-1.21	.234	-.276	11
12	Chemical treatment	-.98	.336	-.241	12
13	Check make up float valve operation and adjust if necessary	-.86	.396	-.207	13
14	Close the drain valve and open make up water valve	-.70	.489	-.138	14

Out of fourteen proposed maintenance activities, only six were identified as significant maintenance requirements in the cooling tower. The most consideration in cooling tower should be given to the entering and leaving temperature of the cooling tower water. Cooling tower has the ability to decrease about 5 ^{O}C from the entering temperature, thus it vary with the climatic deviations.

Bearing speed plays a vital part in lubrication frequency. Most of the blowers are run at the much higher speed further higher speed requires more frequent lubrication. According to the opinion of the experts standard field practice is most commercial service companies perform maintenance in lubricating bearings 4 times a year.

Cleaning of cooling tower surface and fins has a direct relationship with its efficiency because growth algae disturb the heat transmission. Therefore, cooling tower should be regularly cleaned using high pressure water. Condition of the cooling tower fan has a notable relationship with the efficiency of heat transmission of the water. Usage of energy and rotation speed of the fan needs to match with the functional requirement.

Pumps

According to survey analysis there are eight important maintenance activities for pump maintenance (Table 5). Among the proposed fourteen activities, six are not consider as important and not significantly practice in the industry.

Table 5: Maintenance requirements for Pumps

Factors		95% Confidence Interval of the Difference			
		t- Value	**Significance**	**Mean Rating**	**Rank**
1	Lubricate bearing	-3.80	.001	-.767	1
2	Check and replace grease motor and pump bearing	-3.75	.001	-.700	2
3	Visual Inspection	-3.07	.005	-.633	3
4	Vibration Monitoring/Analysis	-2.57	.016	-.533	4
5	Water pump in/ out pressure	-2.52	.017	-.600	5
6	Test run and check for abnormal vibration and noise	-2.47	.019	-.600	6
7	Wear Particle Analysis	-2.44	.021	-.533	7
8	Check drain lines	-2.31	.028	-.467	8
9	Check the condition of valve and fittings	-1.54	.134	-.333	9
10	Lubricant, Fuel Analysis	-1.50	.143	-.333	10
11	Check tension of belts and adjust pulley over heating	-1.45	.155	-.367	11
12	Pump current consumption (Amp)	-1.41	.167	-.400	12
13	Bearing, Temperature/Analysis	-1.35	.186	-.333	13
14	Ultrasonic Noise Detection	-.92	.362	-.167	14

In central air conditioning system, condenser water pumps and the chill water pumps play a major role. Lubrication of bearing has identified as the most necessary maintenance activity. The impeller and the shaft of the pump move with the use of bearings, thus lubrication is required to smooth rotation and to avoid wear and tear. Vibration analysis and noise analysis details can be used to forecast possible failures of a pump. When rotating equipment is installed, an initial vibration analysis provides a baseline for future comparative reviews. There are number of numerous reasons for increased vibrations, such as worn shaft, worn bearing, chipped impeller, failed motor insulation, lost balance weight and dirt on the fan blades.

According to the practitioners view, practising daily visual inspections aiming at detecting signs of possible fault, for example, oil or coolant leaks, structural cracks, or cutting-edge wear is important. This also includes the mechanical adjusting and tune-up of equipment and the detection and correction of small problems before they become major problems. Items requiring attention should be reported. As well as equipment failures occur due to wear outs and random causes. While random failures cannot be eliminated totally, wear out failures can be eliminated by preventive maintenance operations.

3.2.2. SPLIT TYPE A/C SYSTEM MAINTENANCE

T-test results emphasised that five maintenance activities for split type A/C maintenance were important (Table 6). Among the proposed ten activities, five are not consider as important and not significantly practice in the industry.

Table 6: Maintenance requirements for Split A/C system

Factors		95% Confidence Interval of the Difference			
		t- Value	Sig:	Mean Rating	Rank
1	Cleanliness of filters	-3.62	.003	-1.00	1
2	Current amperage	-3.16	.007	-.66	2
3	Check and clean evaporator fan motor and lubricating motor bearing and moving parts	-2.86	.013	-.80	3
4	Check corrosion of base plate and cover of condenser and paint using anticorrosion paints if necessary	-2.46	.027	-.66	4
5	Clean condenser blower and lubricating	-1.52	.150	-.53	5
6	Pressure washing of condenser coil and chemicals if necessary	-1.41	.178	-.53	6
7	Visual inspection for proper refrigerant charge- (liquid line- Warm) , (Suction line- Sweaty)	-.96	.353	-.33	7
8	Clean air filters and inner grill cover	-.96	.353	-.33	8
9	Check blower fan and make necessary adjustments	-.61	.550	-.20	9

If air filters are not clean it affects the distribution of air by the split A/C system. Air filters need to be cleaned with use of a vacuum cleaner or they can be washed. Air filters should be replaced if necessary. By replacing filters often, can remain pure air and healthy against bacteria that can be harmful to lungs. Fresh replacements keep the HVAC system running correctly by extending its lifespan and reducing utility bills by keeping properly maintained. Should inspect filters at least once a monthly to see if need cleaning or replacement. If not conduct the maintenance routinely, the system will have to work extra hard, reducing performance and increasing cost.

When electric motors are subjected to voltages which below the nameplate rating, some of the characteristics will change slightly and others will change more dramatically. A basis point is to drive a fixed mechanical load connected to the shaft a motor must draw a fixed amount of power from the power line. The amount of power the motor draws is roughly related to the voltage current (amps). Thus, when voltage gets low the current must get higher to provide the same amount of power. The fact that current gets higher is not alarming unless it exceeds the nameplate current rating of the motor. When amps go above the nameplate rating it is safe to assume that the build-up of heat within the motor will become damaging if it is left unchecked. If a motor is lightly loaded and the voltage drops the current will increase in roughly the same proportion that the voltage decreases.

3.2.3. PACKAGE A/C SYSTEM

T-test identified two important maintenance activities for split type A/C maintenance (Table 7). Furnace filters not only screen out unwanted pollens and debris from HVAC systems, but also increase the system's productivity. Moreover cleaning and adjustment of the equipment can be reduced the down time and repair costs. As well as replacing of filters and belts cause to create a healthier indoor work environment and optimal running efficiency. In addition it is more important to keep the evaporator coil free of dust, dirt, and debris because these materials act as a layer of insulation and reduce the system’s ability to cool the air that flows across the evaporator coil.

Table 7: Maintenance Requirements for Package A/C System

Factors		95% Confidence Interval of the Difference			
		t- value	Significance	Mean Rating	Rank
1	Clean air filters for accumulated dirt by a vacuum cleaner or washing in water/ replace air filters if necessary	-5.17	.000	-1.067	1
2	Clean evaporator blower and straight damaged fins using fin comb	-4.52	.000	-.933	2
4	Clean condenser inner tube by circulating a diluted acid and straight damaged fins using fin comb	-1.82	.089	-.467	3
3	Check evaporator fan for a loosed v belts and abnormal sounds	-1.04	.313	-.333	4

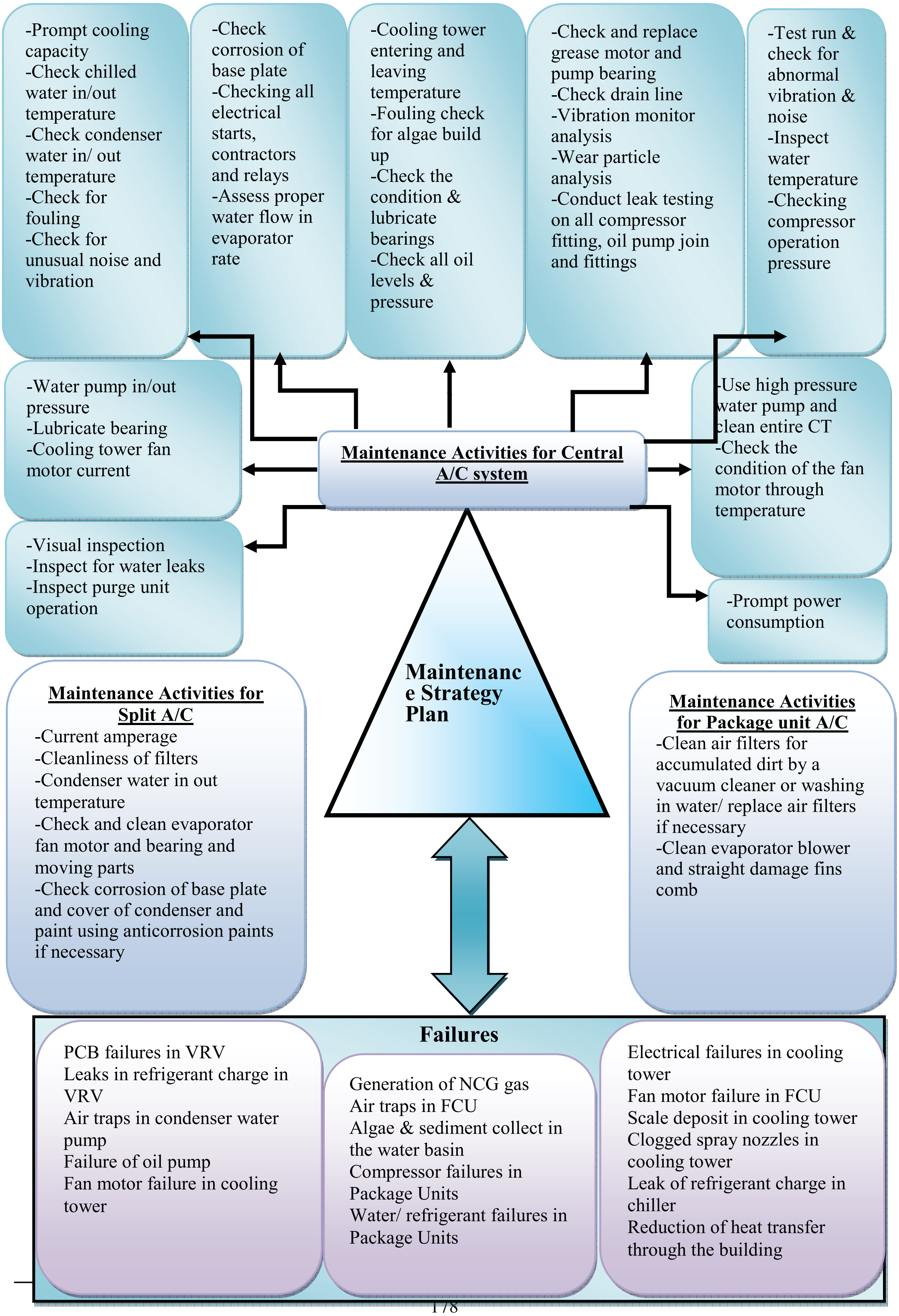
4. CONCLUSIONS

Properly managed maintenance strategic plan of HVAC system will be optimizing the building comfort level, providing less down time and repair costs, providing healthier indoor work environment and optimal running efficiency, maximizing energy cost while maintaining a comfortable work environment and equipment runs more efficiently as well as extends the life time of the equipment.

According to findings preventive maintenance strategy was practiced by most of the organisations. Among the proposed maintenance activities some were identified as significant for the operation of the system. Thus, findings emphasised list of preventive and predictive maintenance activities in order to optimise the energy efficiency of HVAC system.

Maintenance can be used to minimize the maintenance cost, premature failures of building components, cost of maintain testing equipment, sudden maintenance, requirements of staff training, impact for safety of the equipment (durability) and the health and safety requirements. Therefore, a maintenance strategy plan was developed considering preventive maintenance, predictive maintenance strategies. Maintenance plan shows the most important preventive and predictive maintenance activities for central A/C system, split A/C system and package A/C system. The proposed plan may be useful for building managers to manage energy by adopting efficient maintenance strategies.

3.3. *MAINTENANCE STRATEGY PLAN*



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