Most Occurred Faults in Chilled Water System: An Empirical Predictive Maintenance 4.0 Study

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Abstract

Predictive maintenance shows significant impact in managing and controlling the utility systems of commercial buildings. Here in this paper, the predictive maintenance that is in line with Industry 4.0/ Quality 4.0 is applied. The chilled water system is highlighted in this research and the main goal is to reach out the most occurred faults in one of the chilled water system, which is cooling tower. An engineering management framework was used through three parts, set up, machine learning, and quality control. Having said machine learning, decision tree algorithm is used in this research and prediction model showed high prediction accuracy. During an empirical period, the most occurred faults were malfunctioning blowdown system, over current, and low water basin level.

Keywords
Faults, Predictive Maintenance 4.0, Commercial Buildings, Chilled Water System, and Cooling Towers

1. Introduction and Research Objective

Nowadays, the commercial buildings are filling most of the countries' grounds. The owners of these buildings are obviously spending a lot of efforts in establishing polices and strategies to maintain the same. One of these strategies the operation and maintenance, and this research is addressing the predictive maintenance that in line with Industry 4.0 and Quality 4.0. Predictive maintenance is defined a managerial way that is optimizing the availability of a particular equipment, machine, or system (Kullu and Cinar 2022). Having said a particular system, chilled water system is addressed here in this paper. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defined the components of chilled water system and presented the operational way of the said system (ASHRAE 2021). They listed the chilled water system onto four different components as shown in Figure

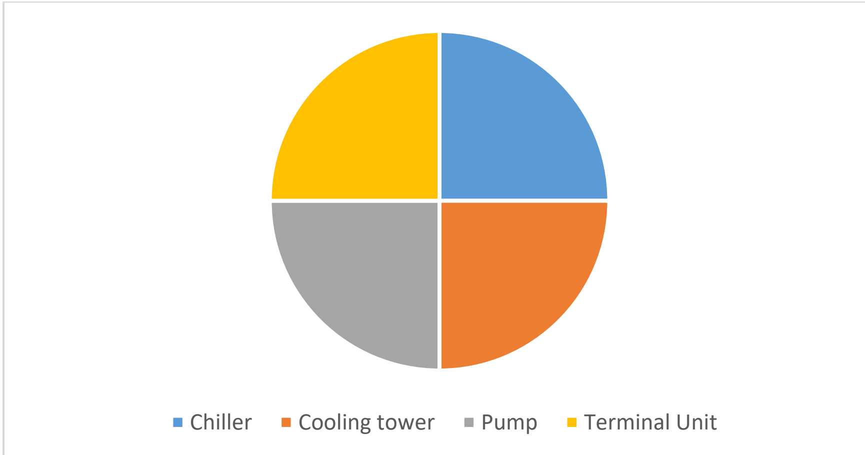

Figure 1. Chilled Water System Components

The operation of chilled water system begins with chillers making the chilled water required to operate the terminal units like air handling unit or fan coil unit and then to achieve the designed building areas conditions. Chillers and primary chilled water pumps are operated and sequenced to make chilled water at a set temperature, whereas a specified temperature of water required by the condenser component of chillers is made by the cooling towers through the condenser water pumps. The chilled water that was made is then pumped by the secondary water pumps to all the terminal units, and in the situation of a variable flow system, the speed of the said pumps is monitored to maintain a set differential pressure in the piping network. Finally, the terminal units receive the chilled water and control their respective valve actuators to accomplish the desired temperatures inside the rooms of the commercial buildings that they are serving.

This goal of this paper is to propose a way to identify what are the most faults are occurring while operating the chilled water system, and the component chosen here in this paper is the cooling tower. So, this goal can be considered as a research question that will be answered by an empirical study.

2. Literature Review

Following a systematic literature study on predictive maintenance 4.0 applications on cooling towers, this component was not given that much attention in research point of view though it is too important (Almobarek et al. 2022). A research study developed an industrial engineering approach via simulation model to predict three faults (Ahn et al. 2001). Two more studies used simulation model to assess multiple faults of cooling towers (Motomura et al. 2019). Another study used a regression model to predict air fan degradation fault by formulating the performance index of the air flow rate reduction (Zhou et al. 2009). Researchers collected data on fan power to detect the same fault by using support vector machine algorithm (Hu et al. 2018). A different research discussed another fault, which is fouling of fills, and predicted it very well by using a regression model (Khan and Zubair 2004). The said two faults (fouling of fills and air fan degradation) can be detected significantly by using the hybrid quick search method through characterizing the performance indices of multiple operational parameters like the inlet water temperature (Ma and Wang 2011). Air fan faulty was again predicted by other researchers using support vector machines algorithm (Sulaiman et al. 2020).

Human factors are clearly affecting predictive maintenance costs and its scheduling. In this regard, a study discussed the failure conditions of a particular cooling tower by introducing a process resilience analysis framework via machine learning (Jain et al. 2019). Another study developed a generalized stochastic Petri net model to predict multiple faults, such as those related to fans, including the operational errors caused by humans (Melani et al. 2019). In Spain, a different research study proposed an autonomic cycle of data analysis tasks involving building management system to predict the failures of two cooling towers of an opera palace (Aguilar et al. 2020). In France, another study diagnosed such failures by using SCANSITES 3D system (Piot and Lancon 2012). At the Oak Ridge National Laboratory in the

United States of America, the air fan degradation fault of the high flux isotope reactor was predicted via wireless sensors (Hashemian 2011).

Principle Component Analysis, which is one of the machine learning algorithms, was used to predict the moto degradation (Wang et al. 2010). Kalman Filter algorithm was used as well to predict fan degradation fault (Sun et al. 2013). Further, In China, the same algorithm was used to observe the cooling towers' performance (Sun et al. 2018). Back propagation neural network algorithm was to predict a particular cooling tower's performance and to eliminate the severity of the related faults (Xu et al. 2014). From the shown literature, it is clear that there was not that much attention given to cooling tower component.

3. Methodology

In this paper, Decision Tree algorithm is applied to predict the chilled water system faults and then to identify the most occurred faults. An industry survey study was followed in this paper (Almobarek et al. 2022). Also, a methodological framework has been used here as well to build the maintenance program that will catch the most occurred faults in cooling towers. The framework contains three parts, which are set up, machine learning using decision tree algorithm, and quality control (Almobarek et al. 2023). Table 1 shows the objective of each part. Here in this paper, the focus will be on the machine learning part as it will lead to the faults within a particular commercial building for a selected cooling tower, and then to see which faults are most occurred. This will give the research community a glimpse about such faults and to list some solutions to protect the cooling tower from breakdown.

Table 1. Predictive Maintenance 4.0 Framework

Part	**Main Objective**
Set up	Data Collection for water leaving temperature
Machine Learning	Training the Decision Tree model and test it
Quality Control	Model Evaluation and Cooling Tower Observation

Table 2. Data Collection Plan

Component	**Reading Time Interval**	**Study Period**
Cooling Tower	Every 30 minutes	16 weeks

Table 3. One Day Check Sheet

<table>
<tr><td colspan="6">Component: Cooling Tower #......</td></tr>
<tr><td colspan="6">Day & Date:</td></tr>
<tr><td>Time</td><td>WLT (°C)</td><td>Fault Free (0)
Fault (1)</td><td>Time</td><td>WLT (°C)</td><td>Fault Free (0)
Fault (1)</td></tr>
<tr><td>6:30</td><td></td><td></td><td>14:30</td><td></td><td></td></tr>
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13:30			21:30		
14:00			22:00		
Inspector Name:…………….. Signature:……………………			Inspector Name:………………… Signature:………………………...		

4. Results and Discussion

As mentioned in the previous section, a particular cooling tower at a campus in Riyadh city is chosen. The predictive maintenance framework has been implemented; Figure 2 shows the decision tree without pruning while Figure 3 shows the decision tree outcome of the said cooling tower with a 99.60 percent prediction accuracy. The empirical period is one month time, and the readings were taken during the weekdays from Sunday to Thursday to guarantee actual operational time.

14 faults were found during the said empirical period with occurrence percentages 34%, 29%, 27%, 6%, 3%, and 1% respectively. The first three percentages were for one fault each, while the fourth one was for six different faults and the last one was for five different faults. Table 4 shows the most occurred faults in the said cooling tower and were fixed by going through the solution that are listed by the industry survey study (Almobarek et al. 2022). So, these faults need more attention while operating the cooling tower to avoid any future damage as well as to avoid any extra costs and save the spare parts.

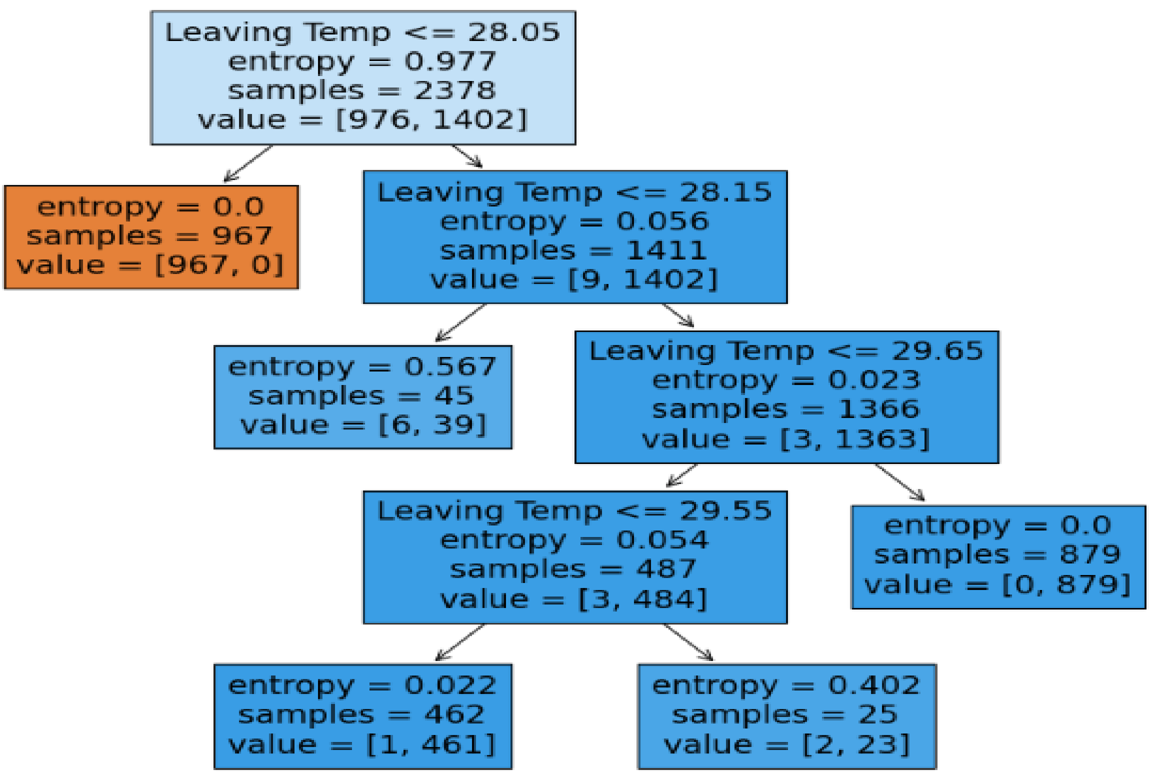

Figure 2. Decision Tree without pruning

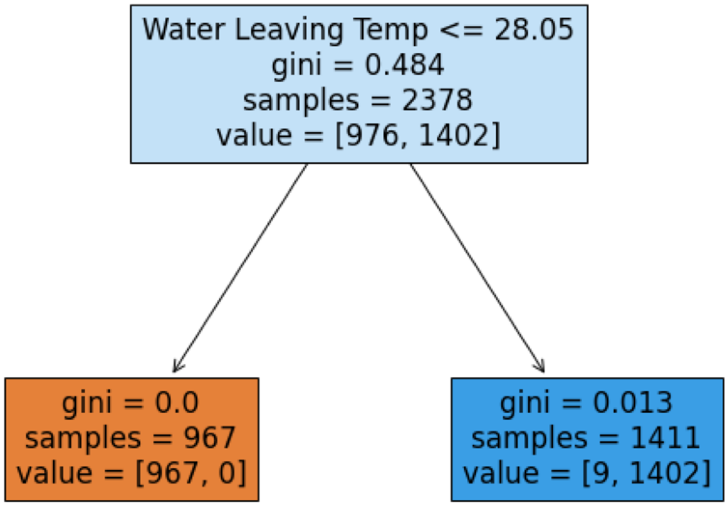

Figure 3. Decision Tree of Cooling Tower

Table 4. Most Occurred Faults

Fault	**Average Occurrence (Day)**
Malfunctioning Blowdown System	Daily
Over Current	2 days
Low Water Basin Level	5 days

5. Conclusion

This paper utilized a managerial framework of predictive maintenance 4.0 for chilled water system in commercial buildings. A particular chilled water system was chosen for an empirical study. The component is the cooling tower, and the goal of the study is to identify the most occurred faults during the associated period. The framework contains three parts, which are set up, machine learning, and quality control. The main objective of the set-up part is the data collection, and the main objective of the machine learning part is the training the prediction model and testing it, while the main objective of the quality control part is to evaluate the prediction model and to make sure the performance is acceptable.

Having said machine learning, decision tree algorithm has been used in this paper and one the universities in Riyadh city, Kingdom of Saudi Arabia, has been chosen to implement the empirical study. The prediction accuracy for the prediction model is high, which is 99.60 percent, and the prediction model showed an outstanding performance in predicting the faults and accordingly in finding the most occurred faults, which are obviously having a negative impact on the cooling tower performance. The most occurred faults during the said empirical period were malfunctioning blowdown system, over current, and low water basin level. By looking at the literature, it can be seen that no research has focused on these faults and the future research agenda can be in this part, so the researchers are advised to do further research on these three faults.

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Biography

Malek Almobarek is a Saudi national. He was born on April 1983 in Kuwait City. He took his primary and secondary education at AlMawardi School where he was a consistent honor student. He graduated in Industrial Engineering from King Saud University in the year 2009. He did assistance to his professors at the same university with tutorial & site visits for the students before starting his experience journey by taking up a job as Plants Equipment Specialist in O&M department at GASCO, Riyadh. He worked there from May 2009 to Sep 2011. He then moved to Dallah Hospital, Dallah Health Co., Riyadh to work as Engineering Department Manager from Sep 2011 to Nov 2013. Thereafter, He joined Alfaisal University as Facility manager in Dec 2013 and currently discharging his duties as Senior Facility Manager. The areas of responsibility in his current job include Buildings and grounds maintenance; Projects; Cleaning; Catering and Leasing; Health and Safety; Procurement and Contract management; Security; Space management; Waste disposal; Mails, Housing and Transportation; Utilities and Campus infrastructure. It is here that he decided to further his studies while continuing to work and joined in Master of Engineering Management (MEM) program that Alfaisal University was offering.

He scored GPA 4.0/4.0 and completed a research thesis on Water Budget Control Framework Using DMAIC Approach for Commercial Buildings. He graduated in April 2020 with a first honor and now is a full time PhD student in Design, Manufacturing and Engineering Management at University of Strathclyde, UK. Eng. Malek is a result oriented, Innovative, resilient, and collaborative. He is not only very good in academics, but also, he is an expert in Facility and Project Management; Procurement and Inventory Management; Supply Chain Management; Emergency Response; Environmental Control; Security Control; Contractor Oversight; Resource Allocation; Building Regulations; Building Systems; Fire Safety; Scheduling; Processes and Procedures; Hazardous Waste, etc. He is a member of Saudi Council of Engineering in the capacity of Professional Engineer and loves travelling, reading, bowling, and watching debates on TV.