International Journal of Marine Engineering Innovation and Research, Vol. 9(4), Dec. 2024. 796-803
(pISSN: 2541-5972, eISSN: 2548-1479)

Optimalization Of Water Cooled Chiller Through Real-Time Data Analysis

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(Received: 23 September 2024 / Revised: 10 October 2024 /Accepted: 10 November 2024 / Available Online: 31 December 2024)

Abstract— **Building heating, ventilation, and air conditioning (HVAC) systems are among the most critical facilities with the most significant energy consumption. This article is based on the issues faced by PT X regarding the importance of visual analytics in energy audits and the performance evaluation of water-cooled chillers and cooling towers. The research methodology used is descriptive qualitative with a quantitative approach, where primary data is obtained based on observations of the machines owned by PT X. The approach taken involves the application of spreadsheets as a system for processing operational data and Looker Studio for real-time data visualization, aimed at understanding performance and energy consumption. The research results show that visualization with the Looker Studio platform provides a solution for PT X to improve the efficiency and effectiveness of the company's performance. In addition, the analysis conducted over six months on the coefficient of performance of a 2,000 TR water-cooled chiller showed a highest value of 21.5 and a lowest value of 13.31, while the highest efficiency of the cooling tower reached 98% and the lowest was 74%.**

Keywords— Coefficient of performance, water-cooled chiller, efficiency, cooling tower, looker studio.

I. Introduction

Heating, Ventilating, and Air Conditioning (HVAC) now account for at least 40% of the building's overall energy consumption and are a critical need for maintaining comfort throughout building operations [1]. HVAC systems can benefit from applying cutting-edge energy-saving technologies to increase energy efficiency [2]. In addition, the application of technology can improve work productivity; therefore, an energy audit system is needed to verify, monitor, and analyze energy usage data, as well as the creation of technical reports aimed at evaluations to improve energy efficiency and reduce downtime [3]. Consequently, the presence of a monitoring system will assist operators in understanding and optimizing room temperature to enhance energy consumption efficiency.

The HVAC system distributes air by regulating temperature, humidity, and cleanliness to provide comfort for occupants and enhance work productivity [4]. Components such as water-cooled chillers and cooling towers are necessary to create a good air cycle for multi-story buildings. A water-cooled chiller as an air conditioning system operates similarly to a vapour compression refrigeration machine, where the cooling system, aided by water and refrigerant, absorbs heat and humidity from the room and releases it into the environment [5]. Meanwhile, the cooling tower has a heat transfer system assisted by atmospheric air and cooling fluid, and the cross-sectional fin design on the radiator tubes in the cooling tower aims to enhance surface heat transfer uniformly [6], [7].

Research on chiller performance has been extensively conducted, focusing on cooling load and energy efficiency. Reducing the cooling temperature can increase the coefficient of performance (COP) of a chiller, according to earlier research on the subject. Temperatures between 20 and 40 °C show that 20 °C produces the optimum COP value of 0.169 [8]. Another study also explains that a higher difference between water supply and water return temperatures will improve the COP of water-cooled chillers [9]. Additionally, different research on the effectiveness of chillers utilizing heat recovery and mass recovery reports that COP and specific cooling power (SCP), which indicate the chiller's cooling capacity per unit of mass flow rate, climbed to 0.607 and 0.393 kW/kg, respectively [10]. Furthermore, research on the effects of fans on the performance and energy consumption of an 800TR water-cooled chiller using R514A refrigerant with six fans found the highest COP value of 8.29 [11]. Another study also examined the impact of decreasing humidity and environmental temperature conditions, which can reduce cooling load energy consumption by 35.12%, thereby improving cooling tower performance [12]. Furthermore, explained that increasing air velocity could enhance cooling capacity by 71.1% with a minor temperature difference between cold water and room air [13].

The research was carried out by conducting interviews with many employees in the technician division of PT X, and we identified several issues related to the performance audit system of the water-cooled chiller. The technician division plays a crucial role in the operation and maintenance of the chiller system, and their insights are invaluable for this research. The issue with the performance audit system of the water-cooled chiller is that workers require time to process and analyze machine data, which is done manually. The data

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expected for analysis includes the coefficient of performance of the water-cooled chiller and the efficiency of the cooling tower to assess the machine's performance continuously. In this research, PT X must provide solutions to help its employees resolve issues. The implementation of problem-solving for the company through technology integration to manage and visualize the work processes of the water-cooled chiller system.

System optimization by implementing technologies such as the Internet of Things (IoT) can help improve performance efficiency and visualize the results of the company's data analysis [14]. Monitoring techniques implemented to provide visibility and a comprehensive understanding of work processes include a dashboard that displays data needs based on key performance indicators, and real-time conditions, allowing parties to identify and resolve issues and perform log analyses that will present processing data sourced from the system [15], [16], [17].

Research on system optimization as an implementation of new technology began with the transition to using the cloud for data warehouse management. It has become increasingly popular due to its advantages, including more flexible scalability than on-premises solutions. With cloud computing technology, storing large amounts of data and achieving integration is possible [18]. Once the machine data can ensure security and flexibility, dashboard-based studies like Looker Studio provide advantages by enhancing the quality and ease of reporting and serving as a quick problem-detection tool through data analysis [19], [20]. Another study explains that visualization dashboards can integrate sensor data, allowing real-time data display [21].

This research is motivated by the need for PT X to improve the performance audit system of water-cooled chillers based on the cloud to manage machine performance data and optimize data sources and data security. The proposed solutions, which include the application of spreadsheets as an audit system for processing the company's operational data and Looker Studio as a visualization tool for real-time conditions, are more than just theoretical concepts. They are practical, implementable strategies that can significantly improve the efficiency and effectiveness of the company's performance in improving the efficiency and effectiveness of company performance in maintaining machine performance and energy efficiency. In addition, the results of this research are also expected to provide practical solutions for other parties or companies facing similar issues in audit systems and data visualization.

II. METHOD

A. Research Object

This research uses a descriptive qualitative method with a quantitative approach to collect and analyze data. Data collection includes secondary data through literature and primary data using direct observation of the operational work parameters, including the input-output temperatures of the condenser and evaporator of the water-cooled chiller and the wet bulb temperature of the cooling tower. This was conducted from July to December 2023, with working hours from 08:00 to 17:00 at building X. Meanwhile, in data processing, it includes statistical analysis using spreadsheets and the use of cloud technology for real-time data collection, as well as the presentation of results which involves data visualization using Looker Studio to display important information. The machine's specifications that are the subject of this research are as follows in Table 1.

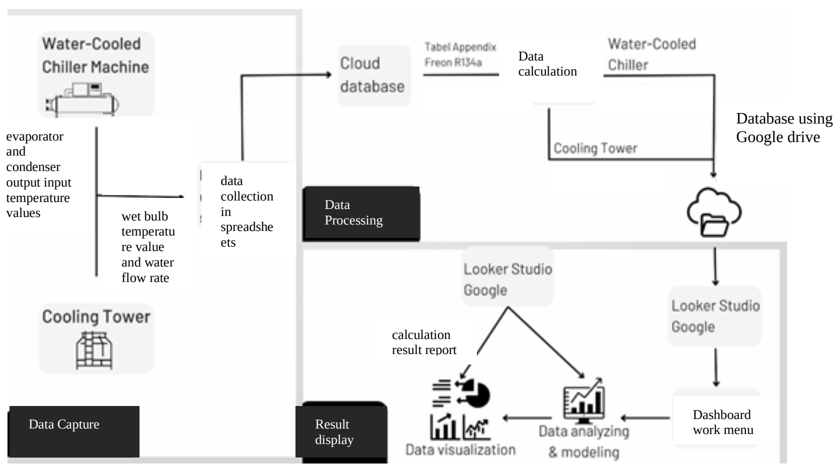


Figure. 1. Research Flowchart

TABLE 1.
SPECIFICATION ENGINE

Specification	Data
Chiller Type Machine	Water Cooled Chiller
Total Capacity	2000 TR
Compressor Type	Free Oil Centrifugal
Refrigerant Type	R134a
AC Voltage	380 V
Phase	3
Frequency	50Hz
Power Input	90kW

B. *Vapor Compression Cycle*

The vapor compression refrigeration cycle, as illustrated, is described as follows [22]:

1. Stages 1 – 2 are an adiabatic and reversible compression process. The refrigerant in the saturated vapor phase exits the evaporator at low pressure and temperature and then enters the compressor to increase its pressure and temperature.
2. Stages 2 – 3 are condensation processes involving isothermal reversible heat release to the environment. In this process, the refrigerant in the vapor phase, which is at high pressure and temperature, is released to the environment to change its phase to liquid.

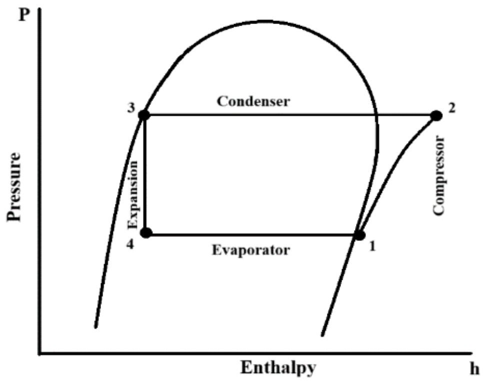


Figure. 2. Vapor Compression Cycle

3. Stages 3 – 4 are an adiabatic and irreversible expansion process. In this process, the refrigerant in the saturated liquid phase at high pressure and temperature is introduced into the expansion device to lower its pressure, resulting in a mixture of gas and liquid phases.
4. Stage 4 – 1 is an isothermal reversible evaporation process in which the refrigerant in the mixed phase absorbs heat from the cooled medium, leading to a phase change into superheated vapor.

C. *Data Collection*

Research on optimizing of water-cooled chiller audits was conducted using Looker Studio, aiming to enhance the efficiency and effectiveness of the company's performance analysis of machinery. This study is the result of calculations and analyses of the coefficient of performance of the water-cooled chiller and the efficiency of the cooling tower, utilizing a cloud database in the form of Google Drive with data processing through spreadsheets based on the Carnot cooling cycle theory with the formula:

$$COP = \frac{h_1 - h_3}{h_2 - h_1} \quad (1)$$

Where COP is the coefficient of performance water cooled chiller, h_1 is enthalpy in the saturated vapor phase (kJ/kg) that occurs in the evaporator output, h_2 is enthalpy in the hot vapor phase (kJ/kg) that occurs in the evaporator input, h_3 is enthalpy in the saturated liquid phase (kJ/kg) that occurs in the condenser output.

$$\eta = \frac{T_{wi} - T_{wo}}{T_{wi} - T_{wb}} \times 100\% \quad (2)$$

Where η is the efficiency of the cooling tower, T_{wi} is the water input temperature of the cooling tower (°C), T_{wo} is the water output temperature of the cooling tower (°C), and T_{wb} is the temperature of the wet bulb(°C).

The research continues by visualizing data processing results using Looker Studio to display data for temperature and enthalpy values, as well as machine efficiency graphs. In addition, Looker Studio provides interactive visualization services, flexible cloud-based monitoring access, and can display real-time data. With general and easily understandable visualization, it supports operators in the decision-making process as the processed data goes through the following stages:

1. Data preparation: Entering and classifying data.
2. Data modeling: Determining the correlations between data tables and calculating measurement results.
3. Data visualization creation: Displaying results in graphs while considering comparisons.
4. Report validation: Testing the conformity of the visualization data against machine standards.

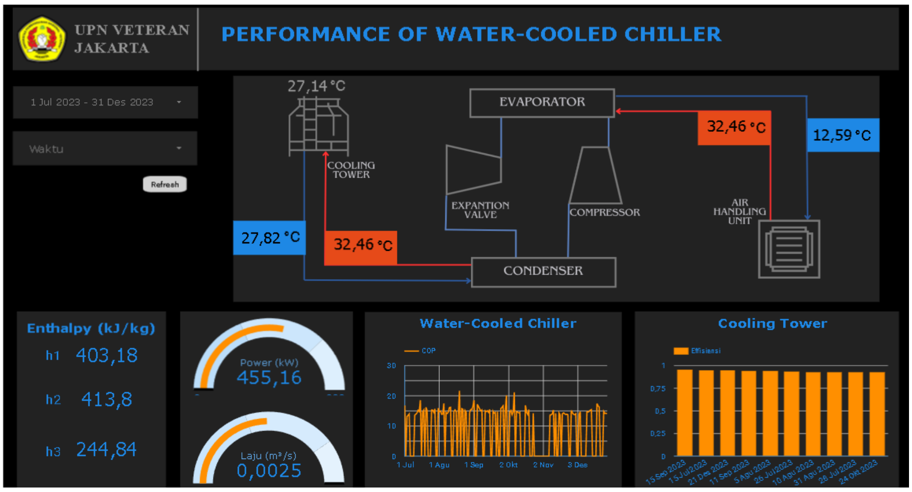


Figure. 3. Looker Studio Visualization

III. Results and Discussion

A. Operational System

To obtain the inlet and outlet temperature data from the evaporator, condenser, and wet bulb, these were gathered through direct observation of the water-cooled chiller and cooling tower with daily average data for each month. Once the temperature data was collected, it was processed through a spreadsheet based on specific time intervals, as in Table 2.

Table 2.
Engine operational data

Month	Time	Tei	Teo	Tci	Tco	Twb
July	08.00	12.8	7.7	26.0	31.8	25.8
	10.00	12.7	7.7	26.5	31.3	26.2
	13.00	12.6	7.7	26.7	32.0	26.2
	14.30	12.5	7.7	27.2	32.2	26.7
	16.00	12.4	7.7	27.1	32.0	26.6
	17.00	15.5	10	25.8	31.6	25.1
August	08.00	12.2	7.9	26.7	31.1	26.6
	10.00	12.2	7.8	26.8	31.2	26.6
	13.00	12.1	8.0	27.6	32.2	27.2
	14.30	12.1	7.7	27.8	32.3	27.2
	16.00	14.1	8.8	26.4	31.9	25.8
	17.00	17.1	11.8	25.9	31.3	25.6
September	08.00	12.4	7.8	26.1	31.0	25.1
	10.00	12.4	6.0	25.8	30.6	25.1
	13.00	12.2	7.9	24.8	29.2	24.6
	14.30	12.3	7.7	24.7	29.4	24.3
	16.00	12.2	7.7	24.8	29.4	24.5
	17.00	14.6	9.3	25.5	31.0	24.5
October	08.00	13.2	8.8	28.2	33.2	27.5
	10.00	13.1	9.8	28.4	31.8	27.9
	13.00	12.1	8.7	28.5	30.6	28.1
	14.30	12.0	8.6	28.5	30.7	28.0
	16.00	13.7	8.0	27.5	32.7	27.0
	17.00	13.7	8.6	26.8	32.1	26.0
November	08.00	13.0	8.4	28.3	33.3	27.3
	10.00	13.1	8.5	28.7	33.7	28.1
	13.00	13.1	8.5	30.0	34.7	29.4
	14.30	13.1	8.5	29.1	34.0	28.4
	16.00	12.9	8.3	28.6	33.6	28.2
	17.00	12.7	8.2	28.4	33.4	27.9
December	08.00	12.7	8.3	28.4	32.4	27.5
	10.00	12.2	8.4	28.3	32.0	27.2
	13.00	12.0	8.4	28.5	32.0	27.3
	14.30	12.0	8.4	28.7	32.2	27.8
	16.00	12.0	8.4	28.5	32.1	27.9
	17.00	12.0	8.4	28.5	32.0	27.5

The table shows that the temperature is not constant during working hours, but some increases are caused by the duration of work and the workload experienced by the water-cooled chiller. The observation results in July showed that the Table 2 evaporator had the highest input temperature of 15.5°C at 17:00 and lowest of 12.4°C at 16:00, while the highest output temperature was 10°C at 17:00 and lowest of 7.7°C per hour. Then, the condenser had the highest input temperature of 27.2°C at 14:30 and lowest of 25.8°C at 17:00, while the highest output temperature of 32.2°C at 14:30 and lowest of 31.3°C at 10:00. In the cooling tower, the highest wet bulb temperature of 26.7°C occurred at 14:30 and lowest of 25.1°C occurred at 17:00.

Observations in August showed that the evaporator had the highest input temperature of 17.1°C at 17:00 and lowest of 12.1°C at 14:30 with a value, while the highest output temperature was of 11.8°C at 17:00 and lowest of 7.7°C at 14:30. Then, in the condenser, the highest input temperature of 27.8°C occurred at 14:30 and lowest of 25.9°C at 17:00. At the same time, the highest output temperature of 32.3°C occurred at 14:30 and lowest of 31.1°C at 10:00. In the cooling tower, the highest wet bulb temperature of 27.2°C occurred at 14:30, and lowest of 25.6°C occurred at 17:00.

Observations in September showed that the evaporator had the highest input temperature of 14.6°C at 17:00 and lowest of 12.2°C at 13:00, while the highest output temperature of 9.3°C at 17:00 and lowest of 6°C at 10:00. Then, in the condenser, the highest input temperature of 31°C occurred at 08:00 and lowest of 24.7°C at 14:30. At the same time, the highest output temperature of 31°C occurred at 08:00 and lowest of 29.2°C at 13:00. In the cooling tower, the highest wet bulb temperature of 25.1°C occurred at 08:00 and lowest of 24.3°C occurred at 14:30.

Observations in October showed that the evaporator had the highest input temperature of 13.7°C at 17:00 and lowest of 12°C at 14:30, while the highest output temperature of 9.8°C at 10:00 and lowest of 8°C at 16:00. Then, in the condenser, the highest input temperature of 28.5°C occurred at 14:30 and lowest of 26.8°C at 17:00. At the same time, the highest output temperature of 33.2°C occurred at 08:00 and lowest of 30.6°C at 13:00. In the cooling tower, the highest wet bulb temperature of 28.1°C occurred at 13:00, and lowest of 26°C occurred at 17:00.

Observations in November showed that the evaporator had the highest average input temperature of 13.1°C and lowest of 12.7°C at 17:00, while the highest average output temperature was 8.5°C and lowest of 8.2°C at 17:00. Then, in the condenser, the highest input temperature of 30°C occurred at 13:00 and lowest of 28.3°C at 08:00. At the same time, the highest output temperature of 34.7°C occurred at 13:00 and lowest of 33.3°C at 08:00. In the cooling tower, the highest wet bulb temperature of 29.4°C occurred at 13:00 and lowest of 27.3°C occurred at 08:00.

Observations in December showed that the evaporator had the highest input temperature of 12.7°C at 08:00 and lowest average temperature of 12°C, while the highest average output temperature of 8.4°C and lowest temperature of 8.3°C at 08:00. Then, in the condenser, the highest input temperature of 28.7°C occurred at 14:30 and lowest of 28.3°C at 10:00. At the same time, the highest output temperature of 32.4°C occurred at 08:00 and the lowest average of 32°C. In the cooling tower, the highest wet bulb temperature of 27.9°C occurred at 16:00, and lowest of 27.2°C occurred at 10:00.

B. Working Analysis Water Cooled Chiller

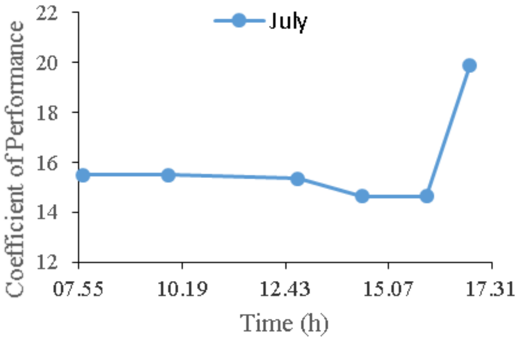
The enthalpy value is taken based on the thermodynamic properties of Freon R134a [23] by entering the enthalpy value into a spreadsheet. After establishing a database, the enthalpy value is determined based on the condenser and evaporator's inlet and outlet temperature values for six months. After knowing the enthalpy value, the equation used to obtain the coefficient of performance value of the water-cooled chiller is:

$$COP = \frac{h_1 - h_3}{h_2 - h_1}$$

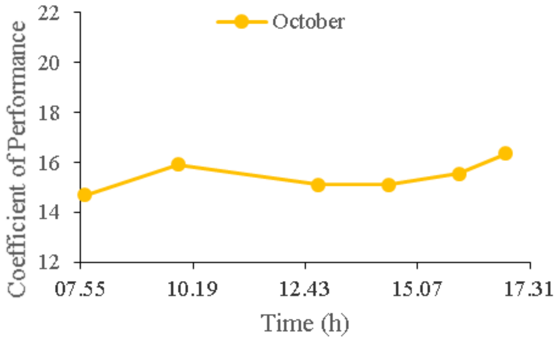
$$= \frac{402.8 - 243.3}{413.1 - 402.8}$$

$$= 15.48$$

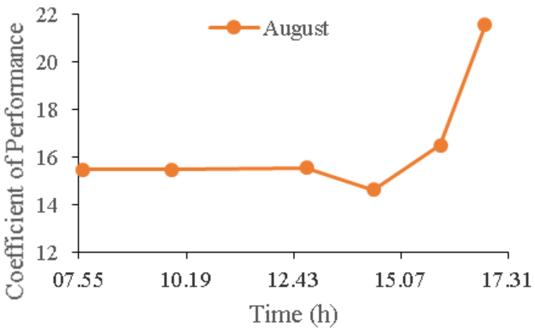
By using the same calculation, do it for different times, then you will get the results in figure 4 as follows:



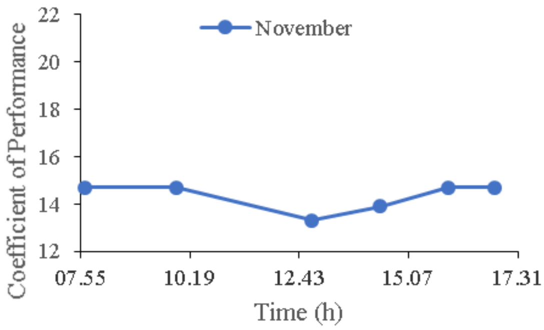
(a) COP – Time Graph in July



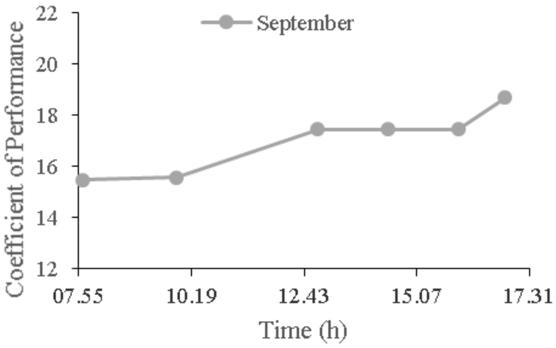
(d) COP – Time Graph in October



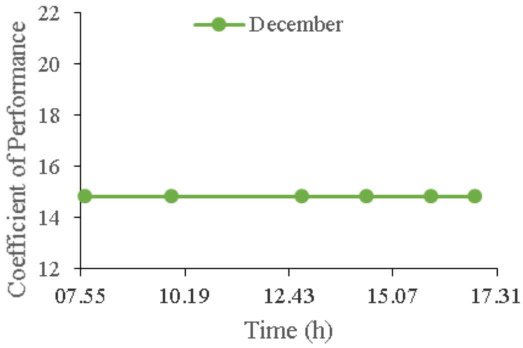
(b) COP – Time Graph in August



(e) COP – Time Graph in November



(c) COP – Time Graph in September



(f) COP – Time Graph in December

Figure. 4. Coefficient of Performance Water Cooled Chiller Graph

Figure 4 shows the considerable value of the coefficient of performance analysis of the water-cooled chiller with a capacity of 2000 TR which is not constant due to the large difference in the input-output temperature of the evaporator and condenser, which causes a difference in the average daily enthalpy value for six months. The calculation results based on the Carnot cooling cycle theory, obtained from the coefficient of performance in July section (a), show that the lowest COP occurs at 14:30 with a value of 14.6 and a significant increase in COP at 17:00 of 19.9, which can occur due to a decrease in cooling load or can be caused by the rise in temperature and humidity of the environment. Then, August section (b) shows that the lowest COP occurs at 14:30 with a value of 14.6 and a significant increase in COP at 17:00 of 21.6, which can occur due to a decrease in cooling load or can be caused by the temperature and humidity of the environment. Furthermore, in September section (c), it shows that the lowest COP occurs at 08:00 with a value of 15.5, and the highest occurs at 17:00 with a value of 18.7. Furthermore, in October section (d), it shows that the lowest COP occurs at 08:00 with a value of 14.7, and the highest occurs at 17:00 with a value of 16.4. Furthermore, in November section (e), it was shown that the lowest COP occurred at 13:00, with a value of 13.3, and the highest average was at 14.7. Also, in December section (f), the average COP was 14.8.

Evaluating the performance of water-cooled chillers through the reference to ANSI/ASHRAE/IES Standard 90.1-2010 concerning energy standard for buildings except low-rise residential buildings, where the minimum efficiency standard for machine capacity> 600TR with a centrifugal type is 0.57 [24]. Therefore, the coefficient of performance of the water-cooled chiller in building x can be stated as efficient. Hence, to maintain the performance of the water-cooled chiller, regular monitoring of its performance is needed, which will help identify potential problems.

C. Working Analysis Cooling Tower

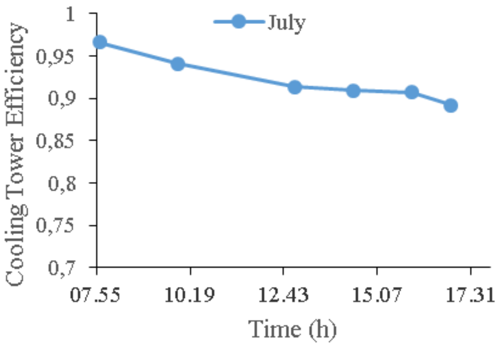
To obtain the Cooling Tower Efficiency value, the input-output condenser temperature data and the wet bulb temperature listed in Table 2 are used. The data is then processed using a spreadsheet using the following equation:

$$\eta = \frac{T_{wi} - T_{wo}}{T_{wi} - T_{wb}} \times 100\%$$

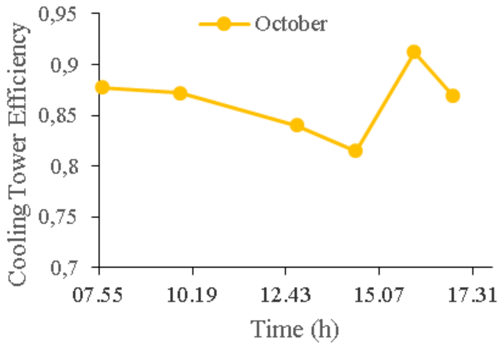
$$= \frac{31.8°C - 26°C}{31.8°C - 25.8°C} \times 100\%$$

$$= 96.6\%$$

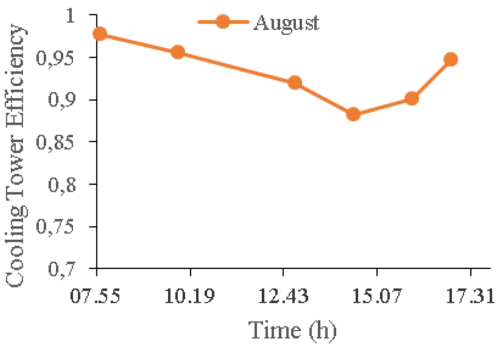
By using the same calculation, do it for different times, then the results will be obtained in Figure 5 as follows:



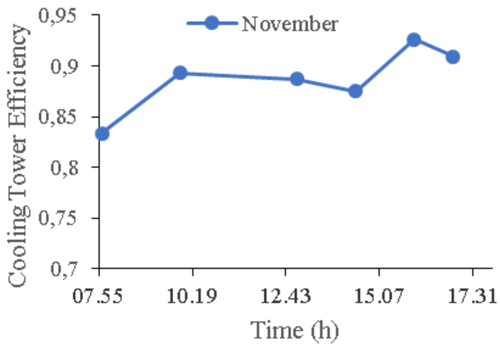
(a) Efficiency – Time Graph in July



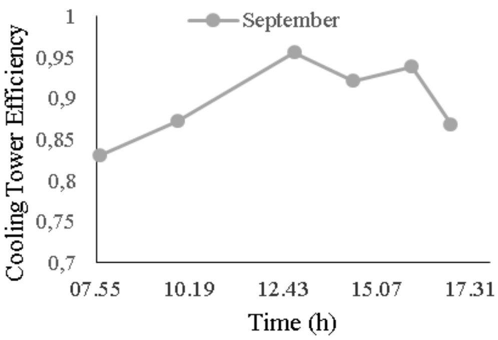
(d) Efficiency – Time Graph in October



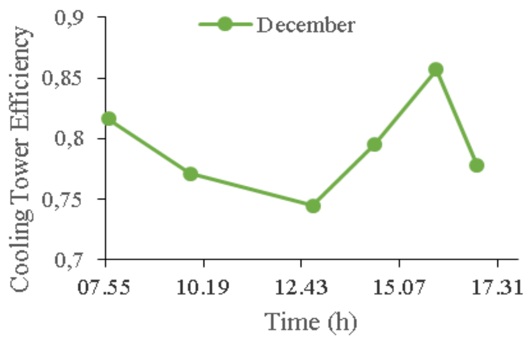
(b) Efficiency – Time Graph in August



(e) Efficiency – Time Graph in November



(c) Efficiency – Time Graph in September



(f) Efficiency – Time Graph in December

Figure. 5. Cooling Tower Efficiency Graph

Figure 5 displays the varying values of the Cooling Tower Efficiency analysis, which is not constant due to differences in the input-output condenser temperatures and wet bulb temperatures, resulting in the fluctuations of the graph derived from daily averages over six months. The calculations based on equation 2 show that the Cooling Tower Efficiency in July section (a) peaked at 08:00 with a value of 0.97 and dropped to its lowest at

17:00 with a value of 0.89. In August section (b), the highest value also occurred at 08:00 with a value of 0.98, while the lowest was at 14:30 with a value of 0.88. In September section (c), the peak was at 13:00 with a value of 0.96, and the weakest at 08:00 with a value of 0.83. In October section (d), the highest value was recorded at 16:00 with a value of 0.91, and the lowest at 14:30 with a value of 0.81. In November section (e), the highest value occurred again at 16:00 with a value of 0.93, while the lowest was at 08:00 with a value of 0.83. Lastly, in December section (f), the peak was at 16:00 with a value of 0.86 and the weakest at 13:00 with a value of 0.74.

In evaluating the efficiency of cooling towers, the significant increases and decreases are caused by several factors, such as a decrease in the cooling load handled by the cooling tower, which will improve efficiency and vice versa. Additionally, changes in temperature and humidity in the environment are contributing factors. Thus, a change in air velocity occurs in the cooling tower.

IV. CONCLUSION

Based on the research findings regarding the optimization of water-cooled chillers through real-time data analysis, the conclusion states that the data visualization dashboard in Looker Studio can display machine performance in real time, thus assisting operators in conducting analysis anytime, anywhere, and by anyone, while also ensuring data security due to the use of cloud as a database, which enhances the company's performance. The analysis results of the Coefficient of Performance of a 2,000 TR water-cooled chiller conducted over six months show that the highest value was in August at 17:00, reaching 21.5, while the lowest was in November at 13:00, reaching 13.31. Meanwhile, the highest cooling tower efficiency was in August at 8:00, reaching 98%, and lowest was in December at 13:00, reaching 74%. Thus, the increase in the temperature difference between input and output and the longer operating time of the water-cooled chiller will affect the rise in the coefficient of performance.

ACKNOWLEDGEMENTS

All praise and gratitude to God Almighty for all the blessings and grace bestowed, allowing the author to complete this research. The author also expresses gratitude to UPN Veteran Jakarta

REFERENCES

[1] T. Daixin, X. Hongwei, Y. Huijuan, Y. Hao, and H. Wen, "Optimization of group control strategy and analysis of energy saving in refrigeration plant," *Energy and Built Environment*, vol. 3, no. 4, pp. 525–535, Oct. 2022, doi: 10.1016/j.enbenv.2021.05.006.

[2] J. Chen, L. Zhang, Y. Li, Y. Shi, X. Gao, and Y. Hu, "A review of computing-based automated fault detection and diagnosis of heating, ventilation and air conditioning systems," *Renewable and Sustainable Energy Reviews*, vol. 161, p. 112395, Jun. 2022, doi: 10.1016/j.rser.2022.112395.

[3] *THE ENERGY CONSERVATION ACT*. Republic of India: Parliament in the Fifty-second Year, 2001.

[4] S. T. Taylor, R. G. Montgomery, and R. McDowall, Eds., *Fundamentals of HVAC control systems: a course reader*, SI ed., Transferred to digital printing. in ASHRA eLearning. Amsterdam Heidelberg: Elsevier, 2009.

[5] Y. Yang, C. Ren, M. Tu, B. Luo, C. Yang, and J. Fu, "Performance analysis for a new hybrid air conditioning system in hot-humid climates by simulation," *International Journal of Refrigeration*, vol. 117, pp. 328–337, Sep. 2020, doi: 10.1016/j.ijrefrig.2020.05.008.

[6] I. Madyshev, V. Kharkov, A. Mayasova, and R. Kurbangaliev, "Cooling efficiency of hybrid cooling tower with finned tube radiator," *E3S Web of Conf.*, vol. 458, p. 01003, 2023, doi: 10.1051/e3sconf/202345801003.

[7] V. Kharkov, I. Madyshev, A. Mayasova, and V. E. Zinurov, "Electrical and Power Engineering (REEPE)," presented at the 5th International Youth Conference on Radio Electronics, 2023, pp. 1–5.

[8] J. Liang, W. Zhao, Y. Wang, X. Ji, and M. Li, "Effect of cooling temperature on the performance of a solar adsorption chiller with the enhanced mass transfer," *Applied Thermal Engineering*, vol. 219, p. 119611, Jan. 2023, doi: 10.1016/j.applthermaleng.2022.119611.

[9] Z. Kang, Z. Shao, L. Su, K. Dong, and H. Liu, "Experimental Study and Energy-Saving Analysis on Cooling Effect with Large Temperature Difference and High Temperature of Chilled Water System in Data Center," in *Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)*, Z. Wang, Y. Zhu, F. Wang, P. Wang, C. Shen, and J. Liu, Eds., Singapore: Springer Singapore, 2020, pp. 933–942.

[10] F. He, K. Nagano, and J. Togawa, "Performance prediction of an adsorption chiller combined with heat recovery and mass recovery by a three-dimensional model," *Energy*, vol. 277, p. 127541, Aug. 2023, doi: 10.1016/j.energy.2023.127541.

[11] A. S. Margana, Susilawati, and Fariyani, "Simulation of the effect of fan cooling tower variations on the performance and energy consumption of water cooled chiller with R-514a as refrigerant," *AIP Conference Proceedings*, vol. 2836, no. 1, p. 100001, Apr. 2024, doi: 10.1063/5.0189060.

[12] H.-L. Park, S.-J. Lee, J.-H. Lee, and J.-W. Jeong, "A liquid desiccant-assisted free-cooling system for energy-efficient data centers in hot and humid climates," *Case Studies in Thermal Engineering*, vol. 52, p. 103683, Dec. 2023, doi: 10.1016/j.csite.2023.103683.

[13] Mi-Su Shin, Sang-Yeop Kim, and Kyu-Nam Rhee, "Cooling capacity evaluation of ceiling radiant cooling panels using thermoelectric module," *Energy and Buildings*, vol. 323, 2024, doi: 10.1016/j.enbuild.2024.114760.

[14] Hathaipree Ngukhiew, "Real Time Production Status Monitoring System," *Science & Technology Asia*, vol. 29, p. 4552, 2024, doi: 10.14456/SCITECHASIA.2024.24.

[15] I. Hristov and A. Chirico, "The Role of Sustainability Key Performance Indicators (KPIs) in Implementing Sustainable Strategies," *Sustainability*, vol. 11, no. 20, p. 5742, Oct. 2019, doi: 10.3390/su11205742.

[16] S. Miguel, F. Maturana, and K. Barton, "Real-time manufacturing machine and system performance monitoring using internet of things," *IEEE Transactions on Automation Science and Engineering*, vol. 15, no. 4, pp. 1735–1748, 2018.

[17] M. Djordjević, B. Jovicic, S. Markovic, and V. Paunovic, "A smart data logger system based on sensor and Internet of Things technology as part of the smart faculty," *Journal of Ambient Intelligence and Smart Environments*, vol. 12, no. 4, pp. 359–373, 2020.

[18] D. Golec, I. Strugar, and D. Belak, "The Benefits of Enterprise Data Warehouse Implementation in Cloud vs. On-premises," *entrenova*, vol. 7, no. 1, pp. 67–76, Dec. 2021, doi: 10.54820/DMZS9230.

[19] B. Yanto, A. Sudaryanto, and Hasri Ainun Pratiwi, "Data Visualization Analysis of Waste Production Volume in Every District of Tangerang Regency in 2021 Using Looker Studio and Big Query Platforms," *JICTAS*, vol. 2, no. 1, pp. 35–40, Sep. 2023, doi: 10.56313/jictas.v2i1.239.

[20] L. Tan, S. S. Ganapathy, K. K. Lim, and N. A. Ahmad, "Development and Utility of an Interactive Online Dashboard for Monitoring Data Collection and Data Processing During a School-Based Health Survey," *Journal of Public Health Management and Practice*, vol. 30, no. 4, 2024, doi: DOI: 10.1097.

[21] S. K. Routray, "Visualization and Visual Analytics in Autonomous Driving," *IEEE Computer Graphics and Applications*, vol. 44, no. 3, pp. 43–53, Jun. 2024, doi: 10.1109/MCG.2024.3381450.

[22] D. W. Green and M. Z. Southard, Eds., *Perry's chemical engineers' handbook*, Ninth edition, 85th anniversary edition. New York, NY: McGraw-Hill Education, 2019.

[23] *Thermodynamic Properties Freon R-134a*. Chemours Company, 2017.

[24] "ANSI/ASHRAE/IES Standard 90.1-2010 (I-P)," 2010.