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Comparative Evaluation of Chiller System Performance with and Without Smart Chiller Control Implementation

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Abstract. Chiller systems are a major component of HVAC systems and account for a significant portion of building energy consumption; therefore, efforts to improve efficiency are required through the implementation of Smart Chiller Control. This study aims to evaluate the performance of chiller systems before and after the implementation of Smart Chiller Control based on cooling capacity, power consumption, Energy Efficiency Ratio (EER), efficiency ratio (kW/TR), and power savings. The study utilized actual operational data from three chiller groups, namely CG03, CG09, and CG15. The results showed that cooling capacity increased from 6,664.17 kW to 8,167.02 kW for CG03, from 8,035.03 kW to 10,894.99 kW for CG09, and from 7,296.20 kW to 8,109.69 kW for CG15. The EER values increased from 14.74 to 15.76 for CG03, from 16.47 to 19.55 for CG09, and from 15.49 to 17.60 for CG15, while the kW/TR values decreased from 0.81 to 0.76 for CG03, from 0.72 to 0.61 for CG09, and from 0.77 to 0.68 for CG15. Baseline predictions using linear regression indicated power savings of 106.73 kW (6.92%) for CG03, 218.57 kW (13.09%) for CG09, and 171.51 kW (11.30%) for CG15. The findings demonstrate that Smart Chiller Control can improve both the performance and energy efficiency of chiller systems.

Keywords: *Chiller, Smart Chiller Control, Energy Efficiency, Efficiency Ratio, Linear Regression, Power Savings.*

A. INTRODUCTION

Chiller systems are a key component in HVAC installations and contribute the largest amount of energy to commercial buildings and industrial facilities. Various studies report that chiller energy consumption can reach 40% of a building's total energy consumption (Karjadi et al., 2025), making improving operational efficiency an urgent need to reduce operational costs and mitigate environmental impacts.

The main problem often encountered with conventional chiller systems is the mismatch between operational strategies and actual load conditions. Most systems still rely on manual, fixed setpoint methods, which cannot dynamically adjust to changes in cooling load (Widyadhana & Suraidi, 2025). Operating at a low Partial Load Ratio (PLR), which is common during most operating hours, causes a significant decrease in COP and increases energy consumption by up to 70% of the total annual energy consumption (Sala-Cardoso et al., 2020). This situation is exacerbated by fluctuating building loads and weather changes, which conventional control systems do not account for.

A data-driven predictive control strategy (Smart Chiller Control) can improve chiller performance by an average of 20% compared to real-time control, by utilizing neural network-based performance maps and short-term load forecasting models (Sala-Cardoso et al., 2020). Karjadi et al. (2025) confirmed that the integration of electronic control, PLC, adaptive algorithms, and intelligent sensing in a multi-stage chiller system can result in 15–21% energy savings, increased COP, and nearly 50% reduction in CO_2 emissions. The study also highlighted that smart control can reduce the frequency of on-off cycling, maintain temperature stability, and extend equipment life. Thus, smart control innovation has proven significant in improving the efficiency and sustainability of large-scale cooling systems (Aritonang et al., 2024).

A study of the implementation of the Automatic Digital Timer Control System (ADTCS) on an air-cooled chiller in Malaysia demonstrated that the automatic control system was able to reduce energy consumption compared to manual operation, demonstrating that even simple control interventions have a significant impact on overall chiller performance (Hussin et al., 2020). Although the technology used is still simple, this study strengthens the argument that implementing automatic control is a fundamental step in improving chiller system efficiency (Rikarda & Mualim, 2026).

The purpose of this study was to analyze the differences in chiller system performance before and after implementing Smart Chiller Control based on cooling capacity, chiller power consumption, and Condenser Heat Rejection. The study also analyzed the effect of Smart Chiller Control on system energy efficiency based on the Energy Efficiency Ratio (EER) and efficiency ratio (kW/TR). Furthermore, this study also aimed to evaluate the magnitude of power savings resulting from implementing Smart Chiller Control by comparing actual power consumption with predicted power consumption obtained using a linear regression method.

B. LITERATURE REVIEW

1. Water Cooled Chiller

A water-cooled chiller is a refrigeration machine that cools water on the evaporator side. A water chiller is a room cooling machine that uses water as a cooling medium circulated within an AHU (Air Handling Unit). The basic principle of a water chiller is the process of absorbing and releasing heat using water cooled in a cooling tower (Muharni et al., 2023). The medium used to cool the water is a refrigerant. Refrigerants are cooling materials used in refrigeration systems, and there are several types of refrigerants depending on the compression system used in the chiller. In every chiller, the condenser plays a crucial role in the cooling process, as it transfers heat from the system to the environment. Water is a good heat absorber, so it can also be used as a cooling medium in the condenser (Pranata et al., 2019).

A water chiller system produces a large amount of chilled water through a cooling cycle. Companies use large amounts of cold water to cool rooms and production machines (Santoso & Mohammad, 2023).

A water-cooled chiller consists of several main components: an evaporator, condenser, compressor, and expansion device. Heat exchange occurs between the evaporator and condenser. Water in a water chiller acts as a secondary refrigerant, absorbing heat from the material being cooled in the evaporator. This water undergoes a temperature change when it absorbs heat and releases it in the evaporator (Pranoto et al., 2023). In general, the refrigerant is compressed in the compressor and then flows to the condenser. The refrigerant flowing to the condenser is at high pressure and temperature. In the condenser, the refrigerant is cooled by the cooling medium in the condenser, causing a phase change from vapor to liquid. The refrigerant then flows to the expansion valve, where the pressure and temperature decrease (Nuriyadi & Margana, 2020).

Chillers and cooling towers are often used to provide cooling energy to commercial and industrial buildings, but they require significant amounts of electricity and water. Numerous studies have been conducted on ways to optimize chiller and cooling tower control to increase efficiency (Yu & Chan, 2008). Chillers are the largest source of energy consumption in most commercial buildings, consuming approximately 40-50% of the total energy used (Firdaus et al., 2018).

A water-cooled chiller system in an air-conditioned hotel can consume approximately a quarter of the total electricity consumption and a significant amount of water in the heat rejection process. (Yu & Chan, 2010) evaluated the operating cost savings of a chiller system integrated with optimal control of the cooling tower and condenser pumps. A sophisticated cooling system model was used to determine how different control methods affected electricity and water consumption. It was estimated that implementing load-based speed control on the cooling tower fan and condenser water pump could reduce annual system electricity usage by 8.6% and operating costs by 9.9% compared to a comparable system using a constant-speed fan and pump with a fixed setpoint of 29.4°C for cooling water temperature control (Andriyuda & Rusirawan, 2024).

2. Smart Control Chiller System

Smart Chiller Control is an intelligent control system that regulates the operation of all chiller plant components (chillers, pumps, cooling towers, valves, and sensors) using automated algorithms to achieve maximum efficiency. This system works by reading operational conditions in real time, analyzing cooling load requirements, and then setting setpoints and optimal equipment settings (Chandra & Wijayanti, 2025). The chiller control system aims to maintain a stable, safe, and efficient cooling process according to cooling load requirements. Its working principle is to read operational conditions in real time and then adjust the chiller components to reach the optimal operating point (Wiharti et al., 2025).

A control system is a mechanism that regulates a process so that its results align with the desired value (setpoint). Conventional controls typically operate based on errors between actual values. Therefore, a smart control system is needed that can automatically adapt to varying operational conditions. The working principle of a smart chiller control is based on the automatic monitoring and regulation of all operating parameters through a data-based control system and intelligent algorithms (Cahyono et al., 2024).

Some of the main principles of this system include:

a. Real-time monitoring
Temperature and flow sensors are installed at various critical points to continuously monitor the chiller's operating conditions (Rinaldo et al., 2026).

b. Automated Analysis and Decision-Making
The obtained data is sent to a Program Logic Controller (PLC), which runs AI-based controls to determine optimal actions (Herdiana et al., 2023).

c. Dynamic Component Adjustment
The controller automatically regulates the speed of the compressor, water pump, and expansion valve using a Variable Frequency Drive (VFD) to maintain maximum efficiency (Pambudi et al., 2026).

The implementation of a smart control system in a chiller offers various benefits in efficiency, operation, and system reliability. This system automatically adjusts the performance of the compressor, pump, and valves according to the cooling load and environmental conditions, resulting in lower power consumption and optimal system performance (Hermnato et al., 2026).

Smart control can increase efficiency and reduce operational costs by adaptively managing power usage. In addition, this system maintains temperature stability and thermal comfort, and extends the life of the equipment due to smoother and less excessive operation (Saputri et al., 2025).

3. Chiller System Analysis Parameters

Chiller system performance assessment is conducted using several parameters. These parameters are used to evaluate performance changes after the implementation of Smart Chiller Control compared to conditions before its implementation (Suhanto et al., 2025). The analysis is based on cooling capacity, efficiency ratio, Energy Efficiency Ratio, Condenser Heat Rejection, chiller power prediction using linear regression, and the percentage of power savings. The evaluation results of these parameters are used to assess the effectiveness of Smart Chiller Control implementation in optimizing the performance and efficiency of the chiller system (Okuana & Umam, 2025).

Table 1. Performance Analysis Parameters

Parameter	Unit
Cooling Capacity	kW
Cooling Capacity	TR
Condenser Heat Rejection	kW
Efficiency Ratio	kW/TR
Energy Efficiency Ratio	(BTU/hr/W)
Chiller Power Prediction	kW
Savings Percentage	%

C. METHOD

This research method uses a quantitative approach by analyzing the actual operational data of three chiller units (CG03, CG09, and CG15) at PT X before and after the implementation of Smart Chiller Control. Data was collected from the monitoring system with a recording interval of every 30 minutes, then compared between the baseline conditions and after the implementation of Smart Chiller Control. Analysis was carried out on various operational parameters, such as temperature, water flow rate, and chiller power consumption, to evaluate changes in the performance and energy efficiency of the system controlled in real time through the integration of an AI-based Programmable Logic Controller (PLC) and a Variable Frequency Drive (VFD).

D. RESULT AND DISCUSSION

1. Data Processing Results

Chiller system operational data was processed to obtain system performance and efficiency parameters used in the study. The calculated parameters included chiller power, cooling capacity, Energy Efficiency Ratio (EER), efficiency ratio, baseline power prediction, and power savings. The data processing results were then grouped based on conditions before and after Smart Chiller Control implementation for each analyzed chiller group, namely CG03, CG09, and CG15.

Table 2. Chiller Performance Data Processing Results

Chiller Name	Condition	Total Cooling Capacity		Total Power	Energy Ratio		Efficiency Improvement
		kW	TR	kW	EER	kW/TR	
CG03	Before	6664.17	1894.84	1544.67	14.74	0.81	6.17%
	After	8167.02	2322.15	1777.82	15.76	0.76	
	Diff				1.02	0.05	
CG09	Before	8035.03	2284.62	1644.16	16.47	0.72	15.27%
	After	10894.99	3097.81	1900.53	19.55	0.61	
	Diff				3.08	0.11	
CG15	Before	7296.2	2074.55	1605.31	15.49	0.77	11.68%
	After	8109.69	2305.85	1572.02	17.6	0.68	
	Diff				2.11	0.09	

Based on table 2, the application of Smart Chiller Control improves performance and efficiency in all analyzed chiller groups. In CG03, the cooling capacity increased from 6664.17 kW to 8167.02 kW with an increase in EER from 14.74 to 15.76 and a decrease in the efficiency ratio from 0.81 kW/TR to 0.76 kW/TR, resulting in an increase in efficiency of 6.17%. In CG09, the cooling capacity increased from 8035.03 kW to 10894.99 kW, the EER increased from 16.47 to 19.55, and the efficiency ratio decreased from 0.72 kW/TR to 0.61 kW/TR, with an increase in efficiency of 15.27%. Meanwhile, in CG15 the cooling capacity increased from 7296.20 kW to 8109.69 kW, the EER increased from 15.49 to 17.60, and the efficiency ratio decreased from 0.77 kW/TR to 0.68 kW/TR, resulting in an efficiency increase of 11.68%. These results indicate that Smart Chiller Control is capable of producing greater cooling capacity with better performance compared to conditions without Smart Chiller Control.

2. Chiller Power Comparison

A comparative analysis of chiller power consumption was conducted to determine the effect of Smart Chiller Control implementation on chiller system usage. Comparisons were made between conditions without Smart Chiller Control and conditions with Smart Chiller Control based on actual operational data. Overall, Smart Chiller Control implementation demonstrated improved chiller system operational performance.

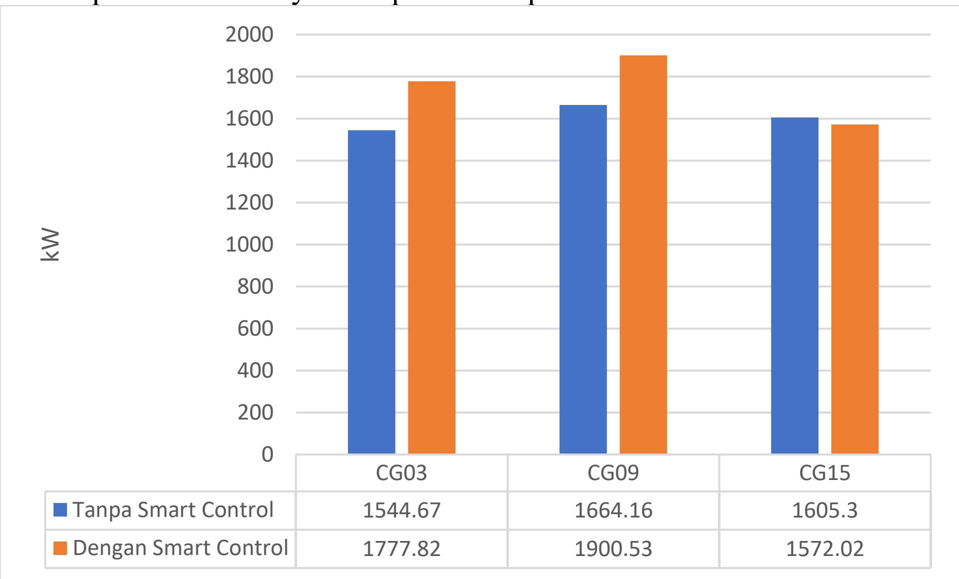

Figure 1. Chiller Power Result Calculation

A comparative analysis of chiller power was conducted to evaluate the effect of Smart Chiller Control implementation on the power consumption of the chiller system. Based on Figure 1, the average power consumption in CG03 increased from 1544.67 kW to 1777.82 kW, while in CG09 it increased from 1644.16 kW to 1900.53 kW after the implementation of Smart Chiller Control. Different from the two units, power consumption in CG15 decreased from 1605.31 kW to 1572.02 kW. Although there was an increase in power in CG03 and CG09, the resulting increase in cooling capacity was greater than the increase in power so that the EER value increased and the efficiency ratio (kW/TR) decreased. This shows that the implementation of Smart Chiller Control is able to optimize system operation and increase overall chiller efficiency.

3. Cooling Capacity Calculation

The cooling capacity calculation is performed to determine the chiller system's ability to absorb the cooling load without Smart Chiller Control and with Smart Chiller Control. The cooling capacity is calculated based on the chilled water flow rate and the temperature difference between the return and supply chilled water in kilowatts (kW) and tons of refrigeration (TR).

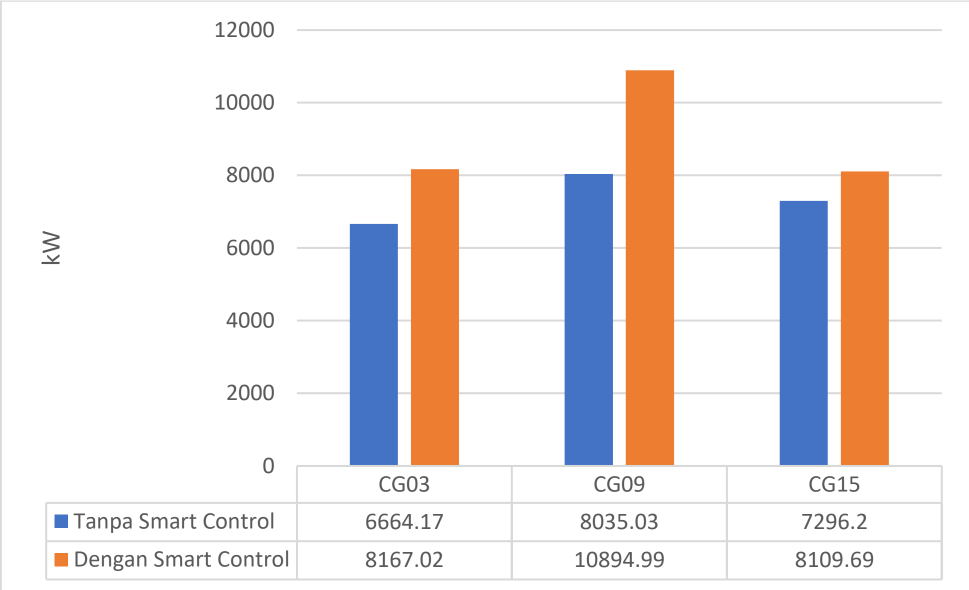

Figure 2. Calculation of Cooling Capacity Results in kW Units

Based on Figure 2, the cooling capacity of all chiller groups increased after the implementation of Smart Chiller Control. The cooling capacity of CG03 increased from 6664.17 kW to 8167.02 kW, CG09 increased from 8035.03 kW to 10894.99 kW, and CG15 increased from 7296.20 kW to 8109.69 kW. These results indicate that Smart Chiller Control is able to increase the system's ability to produce cooling capacity.

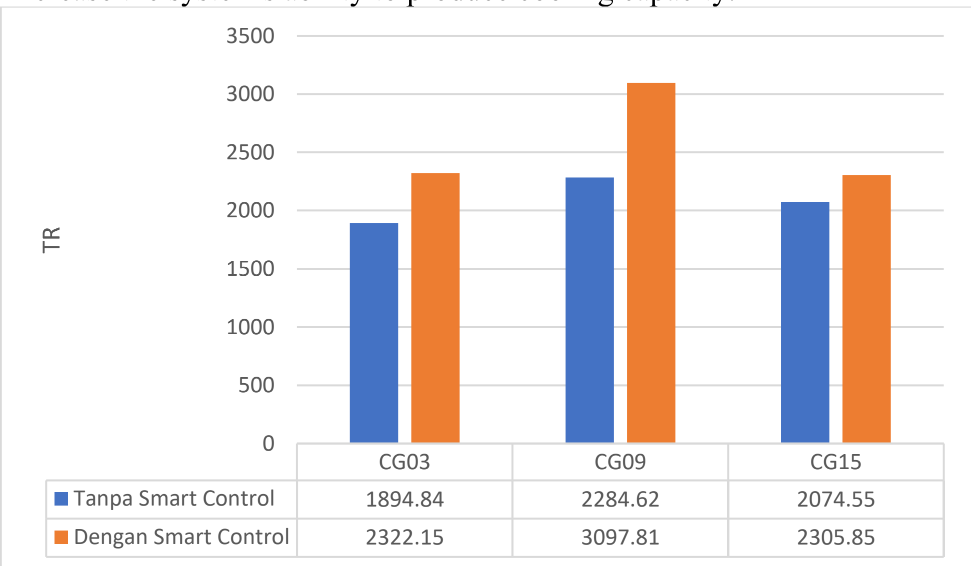

Figure 3. Calculation of the Results of the TR Unit Cooling Capacity

Based on Figure 3, the implementation of Smart Chiller Control increases the cooling capacity of all chiller groups. The cooling capacity of CG03 increased from 1894.84 TR to 2322.15 TR, CG09 increased from 2284.62 TR to 3097.81 TR, and CG15 increased from 2074.55 TR to 2305.85 TR. These results indicate that Smart Chiller Control is able to improve the system's ability to meet cooling load requirements.

4. Calculation of Energy Efficiency Ratio

The Energy Efficiency Ratio (EER) calculation is carried out to evaluate the energy efficiency level of the chiller system under conditions without Smart Chiller Control and with Smart Chiller Control.

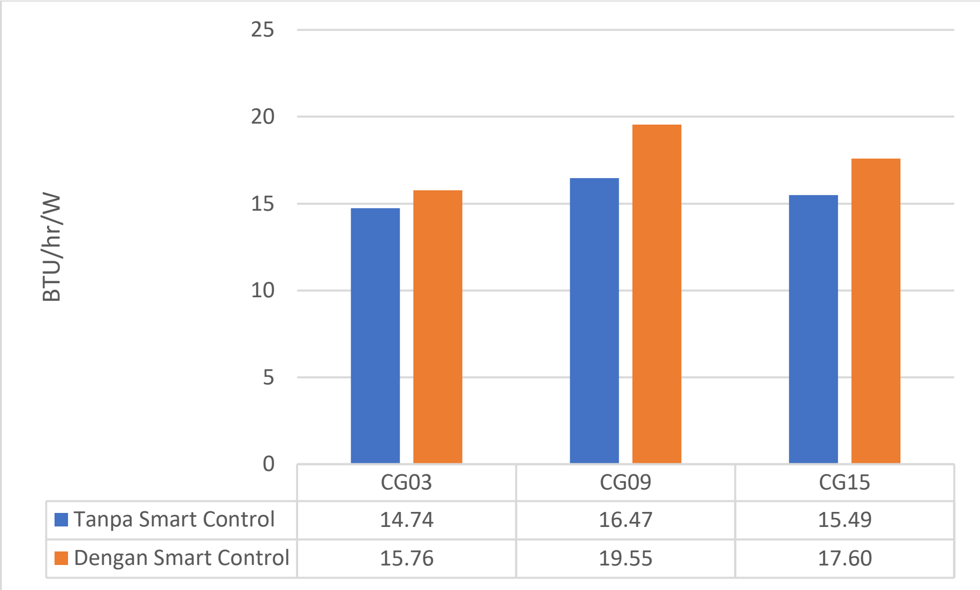

Figure 4. Calculation of Energy Efficiency Ratio Results

Based on Figure 4, the application of Smart Chiller Control provides an increase in the Energy Efficiency Ratio (EER) value in all analyzed chiller groups. The EER value of CG03 increased from 14.74 to 15.76 (Btu/hr)/W, CG09 increased from 16.47 to 19.55 (Btu/hr)/W, and CG15 increased from 15.49 to 17.60 (Btu/hr)/W. The increase in the EER value indicates that the cooling capacity produced by the system increases more than the power consumption used. This result shows that Smart Chiller Control is able to optimize system operation so that the electrical power used can be utilized more effectively to produce a cooling effect.

5. Calculation of Efficiency Ratio

The kW/TR Efficiency Ratio calculation is performed to determine the level of energy usage of the chiller system in relation to the cooling capacity produced under conditions without Smart Chiller Control and with Smart Chiller Control. The kW/TR value indicates the amount of electrical power required to produce one Ton of Refrigeration (TR).

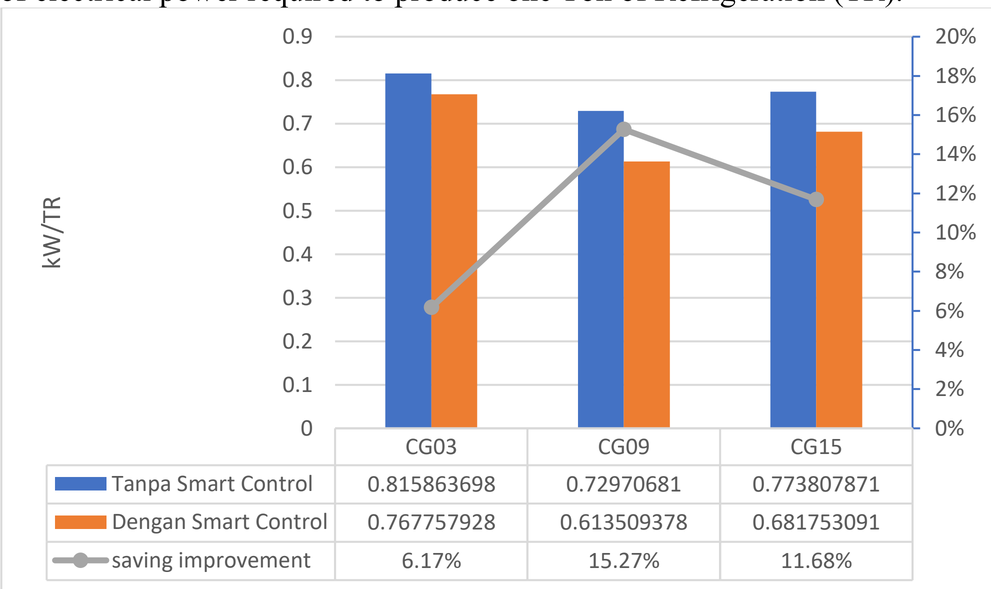

Figure 5. Calculation of Efficiency Ratio Results

Based on Figure 5, the efficiency ratio (kW/TR) value decreased in all chiller groups after the implementation of Smart Chiller Control. In CG03, the kW/TR value decreased from 0.81 kW/TR to 0.77 kW/TR, while in CG09 it decreased from 0.73 kW/TR to 0.61 kW/TR. Meanwhile, in CG15 the kW/TR value decreased from 0.77 kW/TR to 0.68 kW/TR. The decrease in the kW/TR value indicates that the electrical power required to produce one ton of refrigeration is lower compared to conditions without Smart Chiller Control. The largest increase in efficiency occurred in CG09 with a value of 15.27%, then CG15 at 11.68%, and CG03 at 6.17%. These results indicate that Smart Chiller Control is able to improve system performance by producing a greater cooling capacity for the power consumption used.

6. **Comparison of Smart Chiller Power Prediction Linear Regression**

Power predictions are obtained based on a linear relationship between cooling capacity, Condenser Heat Rejection, and chiller power consumption without smart control. These predictions are then compared with actual power under smart control conditions to determine the reduction in power consumption under the same cooling load after implementing Smart Chiller Control.

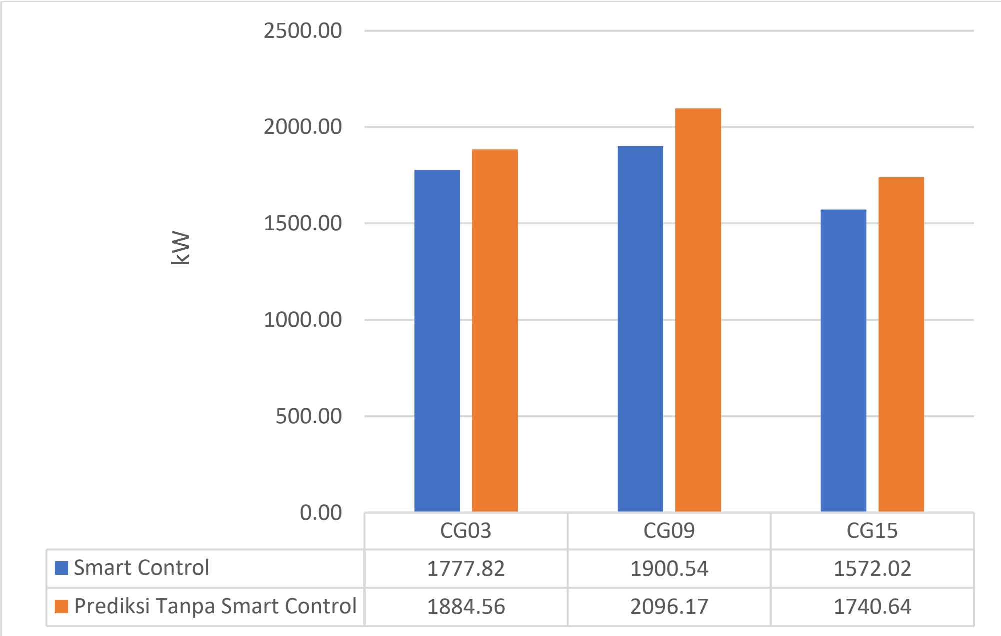

Figure 6. Comparison of Power with Linear Regression

Based on Figure 6, all chiller groups show lower actual power values compared to the baseline power from the linear regression results. In CG03, the actual power of 1777.82 kW is lower than the predicted power of 1884.56 kW. In CG09, the actual power of 1900.54 kW is lower than the predicted power of 2096.17 kW, while in CG15 the actual power of 1572.02 kW is lower than the predicted power of 1740.64 kW. These differences indicate that the implementation of Smart Chiller Control is able to reduce system power requirements under equivalent load conditions. Thus, the baseline linear regression model indicates that Smart Chiller Control contributes to power savings through more optimal system operation compared to conditions without Smart Chiller Control.

7. **Calculation of Savings and Percentage from Regression**

A savings analysis was conducted to evaluate the effectiveness of Smart Chiller Control implementation in reducing system power consumption compared to the Linear condition (without smart control). Savings were calculated based on the difference between the predicted chiller power using the linear regression method and the actual chiller power under smart control conditions.

Table 3. Calculation of Savings Results and Percentage

Chiller	Chiller Power Prediction (Without Smart Control) (kW)	Chiller Power (kW)	Saving (kW)	Saving (%)
CG03	1884,56	1777,82	106,73	6,92%
CG09	2096,17	1900,53	218,57	13,09%
CG15	1740,64	1572,02	171,51	11,3%

Based on Table 3, all chiller groups showed lower actual power values compared to the baseline power obtained from the linear regression. The largest savings occurred in CG09 at 218.57 kW (13.09%), followed by CG15 at 171.51 kW (11.3%), and CG03 at 106.73 kW (6.92%). The difference between actual power and baseline power indicates that Smart Chiller Control is able to optimize the system so that power consumption can be lower without reducing the resulting cooling performance.

E. CONCLUSION

Based on the results of calculations and comparative evaluation analysis of chiller system performance before and after the implementation of Smart Chiller Control, it can be concluded that the implementation of this system is able to improve performance and operational efficiency in all chiller groups studied. The increase in performance is indicated by the increase in cooling capacity, namely in CG03 from 6664.17 kW to 8167.02 kW, CG09 from 8035.03 kW to 10894.99 kW, and CG15 from 7296.20 kW to 8109.69 kW. The increase in energy efficiency is also reflected in the increase in the Energy Efficiency Ratio (EER) value, namely in CG03 from 14.74 to 15.76, CG09 from 16.47 to 19.55, and CG15 from 15.49 to 17.60 (Btu/hr)/W, as well as the decrease in the efficiency ratio (kW/TR) which shows that the need for electrical power per ton of refrigeration is getting lower, respectively from 0.81 to 0.76 in CG03, from 0.72 to 0.61 in CG09, and from 0.77 to 0.68 in CG15. Analysis using linear regression method also shows that there are power consumption savings in all chiller groups, namely 106.73 kW (6.92%) in CG03, 218.57 kW (13.09%) in CG09, and 171.51 kW (11.30%) in CG15 compared to baseline conditions. Overall, the results of the study indicate that the application of Smart Chiller Control is able to optimize the operation of the chiller system through adaptive control to changes in cooling loads by utilizing historical operational data to predict cooling needs, resulting in increased performance and energy efficiency.

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