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Analysis of the Impact of Cooling Water Inlet Temperature Changes on Energy Consumption of a Water-Cooled Centrifugal Chiller in Hotel Buildings in Bali

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Abstract: Global climate change and the increasing energy demand in the hospitality industry have led to greater attention toward energy efficiency and resource management. In Bali, known as one of the world's most popular tourist destinations, hotel buildings rely on cooling systems to maintain guest comfort. Water-cooled centrifugal chillers are widely used in large buildings, including hotels. This study aims to analyze the effect of variations in cooling water inlet temperature on the performance of a water-cooled centrifugal chiller in a hotel building in Bali. The research object is a Mitsubishi Heavy Industries chiller with a capacity of 250 TR using R134a refrigerant. The method used is an experimental study, focusing only on the chiller unit without considering air conditioning and cooling tower performance. The results show that increasing the cooling water inlet temperature raises condenser pressure and electrical energy consumption. At a cooling load of 72%, maintaining the inlet temperature at 27.48°C (below the maximum specification limit) can save 194.4 kWh of electrical energy per day. However, if the inlet temperature reaches 32.05°C (above specifications), energy consumption increases by 199.2 kWh per day.

Keyword: Global Climate Change, Water-Cooled Chiller, Cooling Load, Energy Consumption, Efficiency.

INTRODUCTION

Global climate change and increasing energy demand in the hospitality industry have triggered greater concern for energy efficiency and resource management. In Bali, as a major global tourist destination, hotel buildings depend heavily on cooling systems to ensure guest comfort.

Water-cooled centrifugal chillers are commonly used in large-scale cooling applications, including hotels. These systems operate by circulating water to remove heat from the refrigerant in the condenser. However, their operational efficiency is highly influenced by the cooling water inlet temperature.

Fluctuations in cooling water temperature can cause changes in condenser pressure, which in turn affects overall energy consumption. Therefore, it is important to understand how variations in cooling water inlet temperature impact the performance and efficiency of the chiller system.

This study aims to identify the relationship between inlet temperature and energy consumption in a water-cooled centrifugal chiller used in a hotel building. The findings are expected to help hotel management improve energy efficiency and reduce operational costs.

METHOD

This section explains the research type, subjects, time and location, instruments, procedures, and techniques used.

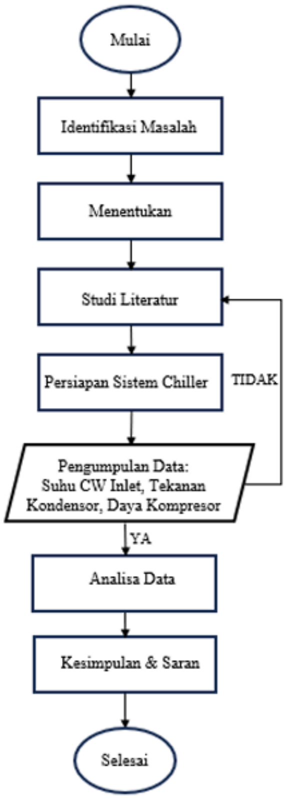


Figure 1. Figure: Research Flowchart Diagram

Tools, Materials and Spesifiaction Data

1) Water-cooled chiller
2) Laptop
3) Thermometer
4) Multimeter
5) USB printer cable

Tabel 3.1 Spesifikasi Unit Chiller

Chilled Water	Inlet Temp	12 °C
	Outlet Temp	7 °C
	Flow rate	150.8 m³/h
Cooling Water	Inlet Temp	30 °C
	Outlet Temp	35 °C
	Flow rate	175.5 m³/h
Tegangan		380 V
Arus		238 A
Daya Input		136 kW
Cooling Capacity		879.1 kW / 250 TR

Research Procedure

The initial step involved collecting chiller design data and determining evaluation parameters such as cooling water inlet temperature, condenser pressure, and compressor power. Next, relevant technical data were collected, followed by data analysis.

RESULT AND DISCUSSION

Results

Cooling Load (Qe)

To calculate the actual cooling load:

1) CHW flow rate: 150.5 m^3/h
2) CHW inlet temperature: 10.6°C (283.75 K)
3) CHW outlet temperature: 7°C (280.15 K)
4) Water density: 1000 kg/m^3
5) Specific heat: 4.2 kJ/kg·K

From these calculations, the percentage of cooling load can be determined.

$$Persentase\ Cooling\ load = \frac{Aktual\ cooling\ load}{Spesifikasi\ cooling\ load} = \frac{632.1\ kW}{879.1\ kW} = 72\%$$

Compressor Power

Using the equation:

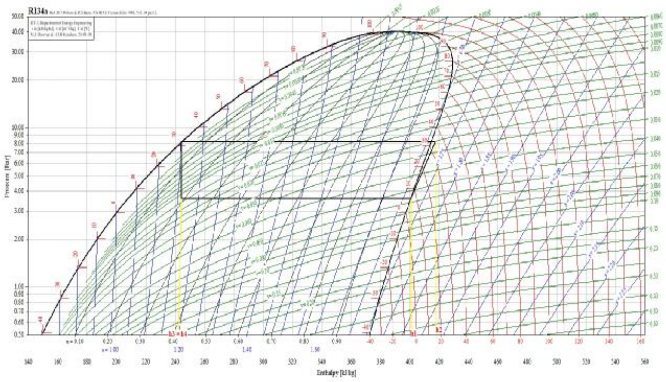
1) Voltage: 380 V
2) Current: 132.1 A
3) Power factor: 0.88

Result:

Compressor power = $Vx\ I\ x\sqrt{3}\ x\ cos\varphi$ P =(380 Volt)×(132.1 A)×(√3 P =76.512 $watt$ = 76.5 kW

Performance Calculation Using p-h Diagram

From the R134a p-h diagram:



Gambar 4.1 P-h Diagram Refrigerant 134a

1) Condenser pressure: 7.15 bar
2) Evaporator pressure: 2.6 bar
3) h_1 = 400.5 kJ/kg
4) h_2 = 417.3 kJ/kg
5) h_3 = 244.3 kJ/kg

The Coefficient of Performance (COP) is calculated using these values.

$$COP_{aktual} = \frac{Energi\ diserap\ di\ evaporator\ (Qe)}{Kerja\ Kompresi\ (W)}$$

$$COP_{aktual} = \frac{156.2\ kJ/kg}{16.8\ kJ/kg} = 9.3$$

Logarithmic Mean Temperature Difference (LMTD)

LMTD at the condenser is calculated based on observed temperature data.

Tabel 4.1 Data Pengamatan Kondensor

No.	Parameter	Nilai	Satuan
1	Tekanan kondensor	7.62	bar
2	Suhu Saturasi (t_c)	34.03	ºC
3	Flow rate	175	m^3/h
4	Suhu CW inlet (t_1)	30.0	ºC
5	Suhu CW oulet (t_2)	33.25	ºC

Thus, the LMTD at the condenser can be calculated as follows,

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{t_2 - t_1}{\ln((t_c - t_1)/(t_c - t_2))}$$

$$\Delta T_m = \frac{33.25 - 30}{\ln((34.03 - 30)/(34.03 - 33.25))} = \frac{3.25}{\ln(4.03/0.78)}$$

$$\Delta T_m = 1.98\ ^{\circ}C$$

Discussion

Relationship Between Cooling Water Inlet Temperature and Condenser Pressure

The data show that condenser pressure increases as cooling water inlet temperature rises. The magnitude of the increase also depends on the cooling load.

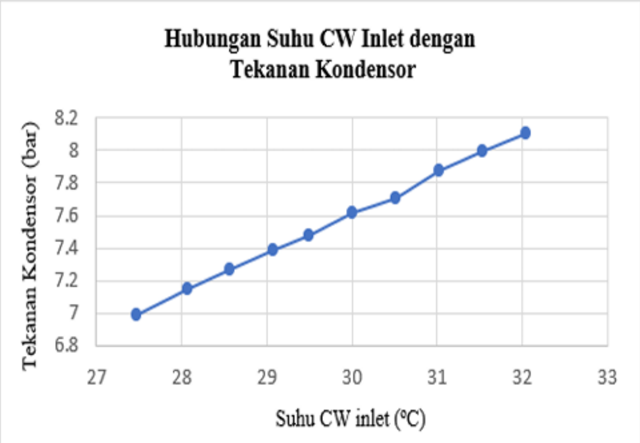


Figure 3. Graph of the Relationship Between Cooling Water (CW) Inlet Temperature and Condenser Pressure at 72% Cooling Load

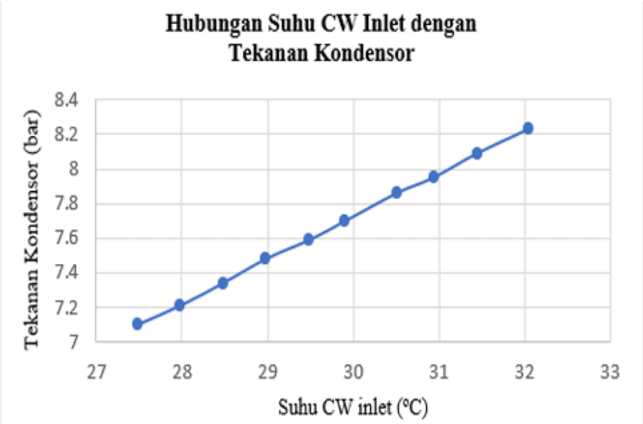


Figure 4. Graph of the Relationship Between Cooling Water (CW) Inlet Temperature and Condenser Pressure at 80% Cooling Load

Based on the two graphs in Figures 3 and 4 above, it is shown that the condenser pressure increases as the CW inlet temperature rises. However, the magnitude of the pressure increase is also influenced by the cooling load. This can be seen when the CW inlet temperature is 30.5°C, where the condenser pressure is 7.71 bar at a 72% cooling load. Meanwhile, at an 80% cooling load with the same CW inlet temperature (30.5°C), the condenser pressure increases to 7.86 bar.

Relationship Between Condenser Pressure and Compressor Power

Based on the data in Tables 2 and 3 above, the relationship between condenser pressure and compressor power is illustrated by the graphs in Figures 5 and 6 below, Compressor power increases as condenser pressure rises, and is also influenced by cooling load.

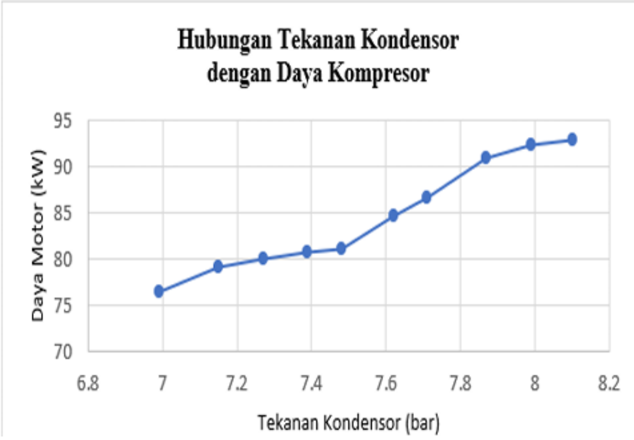


Figure 5. Graph of the Relationship Between Condenser Pressure and Compressor Power at 72% Cooling Load

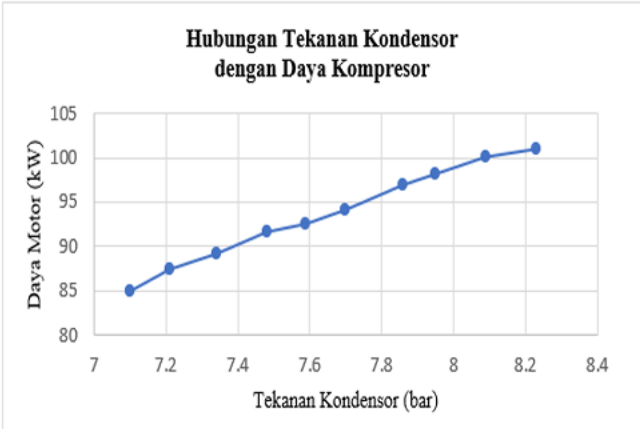


Figure 6. Graph of the Relationship Between Condenser Pressure and Compressor Power at 80% Cooling Load

Based on the two graphs in Figures 4 and 5 above, it is shown that compressor power increases as condenser pressure increases. However, the magnitude of the increase in compressor power is also influenced by the cooling load. The data show that the compressor power is 86.7 kW when the condenser pressure is 7.7 bar at a 72% cooling load. Meanwhile, at an 80% cooling load with the same condenser pressure (7.7 bar), the compressor power increases to 94.1 kW.

Operational Cost Efficiency

Based on the data in Table 4, the electrical energy consumption of the chiller can be calculated under the condition that the chiller operates for 24 hours per day with a constant cooling load of 72%, as follows:

Table 4. Power Values at 72% Cooling Load

No.	Suhu CW Inlet (°C)	Tekanan Kondensor (bar)	Daya (kW)
1	27.48	6.99	76.5
2	30	7.62	84.6
3	32.05	8.1	92.9

Assuming 24-hour operation at 72% load:

1) 27.48°C → 1836 kWh/day

2) 30°C → 2030.4 kWh/day
3) 32.05°C → 2229.6 kWh/day

Based on the calculations above, there is a significant difference in the chiller's electrical energy consumption due to changes in the CW inlet temperature. This means that by maintaining the CW inlet temperature at 27.48°C (below the maximum specification limit of 30°C), electrical energy consumption can be reduced by 194.4 kWh per day. Conversely, when the CW inlet temperature reaches 32.05°C (above the chiller unit specifications), electrical energy consumption increases by 199.2 kWh per day.

CONCLUSION

Based on the research results and discussion, several conclusions can be drawn as follows:

1) An increase in the cooling water inlet temperature will increase the condenser pressure. However, the magnitude of the pressure increase is also influenced by the cooling load. This can be seen in the observation data in Tables 2 and 3. When the cooling water inlet temperature is 27.48°C, the condenser pressure is 6.99 bar at an average cooling load of 72% and 7.1 bar at an average cooling load of 80%. Meanwhile, when the cooling water inlet temperature reaches 32.05°C, the condenser pressure increases to 8.1 bar at an average cooling load of 72% and 8.23 bar at an average cooling load of 80%.
2) As the condenser pressure increases, the compressor power also increases. However, the magnitude of the power increase is influenced by the cooling load on the chiller. This is shown in the observation data in Tables 2 and 3. When the condenser pressure is 7.48 bar, the compressor power is 81.1 kW at an average cooling load of 72%. At the same pressure, the compressor power increases to 91.7 kW at an average cooling load of 80%.
3) Electrical energy consumption can be reduced by maintaining the cooling water inlet temperature below the chiller unit specifications. Based on the observation data in Table 4.4, when the cooling water inlet temperature is 30°C, the energy consumption is 2030.4 kWh per day. If the cooling water inlet temperature is maintained at 27.48°C, the energy consumption decreases to 1836 kWh per day. This represents a reduction of 194.4 kWh per day when the chiller operates continuously for 24 hours.

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