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The Influence of Optimizing the Difference of Water Flow Rate to Energy Efficiency in Water Cooled Plant System

Dany Watanabe and Wegie Ruslan

Department of Mechanical Engineering, Atma Jaya Catholic University of Indonesia, Jakarta, Indonesia.
Jalan Jenderal Sudirman no.51, Setia Budi-South Jakarta (12930), Indonesia.

Abstract

To reduce the use of electrical energy as a result use of chilling machines that increase in a building, modification of mass flow rate difference is conducted. This study comparing the rate of water flow based on AHRI standard with low flow system. The method used is divided into three water cooled plant system parts: (1) cooling machine systems in parallel with a constant flow rate at the side of the chilled water and constant flow rate at the side of the cooling tower (2) cooling machine systems in decoupled with a constant flow rate at the side of the chilled water, variable flow rate at the side of the cooling tower and use secondary pump with variable flow rate (3) cooling machine systems in dedicated with variable flow rate at the side of the chilled water and variable flow rate at the side of the cooling tower. Modification of water mass flow rate difference was aimed at knowing the magnitude of the water pressure drop and electric energy consumption in chiller, pump at the side of the chilled-water, pump at the side of the cooling tower and the cooling towers. Through the comparison of the flow rate system, the lowest electrical consumption is by using low flow rates with cooling machine system in dedicated (variable flow rate at the side of the chilled-water and variable flow rate at the side of the cooling towers).

Keywords: differences of water flow rate, water cooled system, AHRI, low flow, energy consumption

INTRODUCTION

Refrigeration is a process of moving heat from one location to another in a controlled condition, this system allows to set the temperature until it reaches temperatures below the temperature of the environment. The use of refrigeration is very well known on the air conditioning systems in building, transportation and preservation of a food ingredient and beverages. Refrigeration system is known for two cycles: vapor compression refrigeration cycle and absorption refrigeration [1].

Basically the use of Heating, Ventilating and Air Conditioning (HVAC) on building aims to create and maintain a comfortable environment inside a building. Some of the comfort requirements relating to HVAC system are: the dry air temperature, humidity, air movement, the freshness of the air, the cleanliness of the air and the noise level. Currently, in doing a building cooling system design, has led to a eco-friendly planning based and more efficient energy consumption.

Based from that, the modification of flow rate on the water cooled plant system has been done as one of the alternatives in energy savings with a reduction in the use of electrical energy.

BASIC THEORY

In the refrigeration cycle requires four major components, namely: compressor, evaporator, condenser and the expansion valve. Refrigeration cycle diagram that shows the relationship between these components is called the P-H (pressure-enthalpy) diagram.

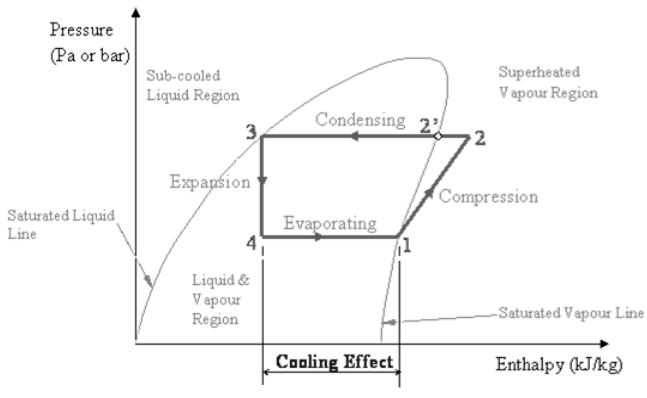

Figure 1: p-H Diagram of Vapor Compression Cycle Standard

In the p-H diagram above, the refrigerant is experiencing four processes, i.e.:

Process 1-2:

Reversible adiabatic compression, is a dry compression (in a state of superheated vapor), that goes inside the compressor. Refrigerant in the suction by the compressor, in the form of saturated vapor with low temperature and pressure conditions. Then by the vapor compressor, the refrigerant pressure is raised and turns into a vapor phase in the superheat conditions.

Process 2-3:

Heat dissipation at constant pressure in reversible desuperheating and condensation

Process 3-4:

Irreversible expansion at constant enthalpy, saturated liquid phase to evaporative pressure

Process 4-1:

The reversible absorption of heat at constant pressure for evaporation to the saturated vapor.

An indicator of efficiency in a refrigeration cycle is coefficient of performance (COP), where is defined as the heat absorbed from the cooled space divided by the input work of compressor [2].:

$$COP = \frac{\mathrm{Ql}}{\mathrm{W}}$$

Q1 = Cooling capacity (kW), W = Compressors work (kW)

The rate of cooling water can be calculated with the following equation:

$$Q_{water} = \dot{m}_{water}.Cp.\,(T_{end}-T_{beginning})$$

Q_{water} = cooling capacity (kW), $\dot{m}_{water}$ = mass flow rate (kg/s), Cp = heat capacity (kJ/kgC), T = temperature (C)

In this design there are three water cooled plant system:

a. The cooling system in parallel
   For more details, can be defined below:

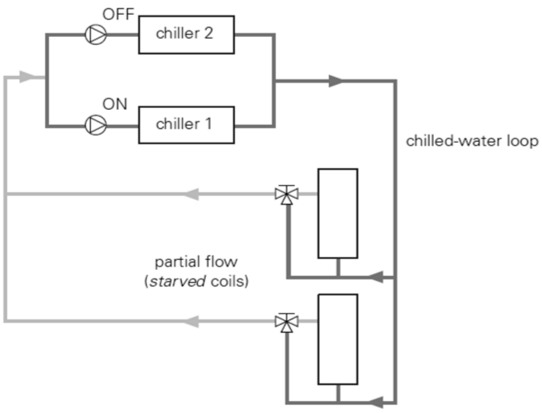

Figure 2: Parallel chillers

In this cooling system, every each network of chiller has one pump and each in parallel concatenation. When there is a load of coolers with low capacity, a chiller works first. When the capacity of the load exceeds the capacity of the first chiller, then another chiller will work together and divide the burden proportionately. Each pump works with full flow rate conditions constantly[3].

b. The cooling system in decoupled

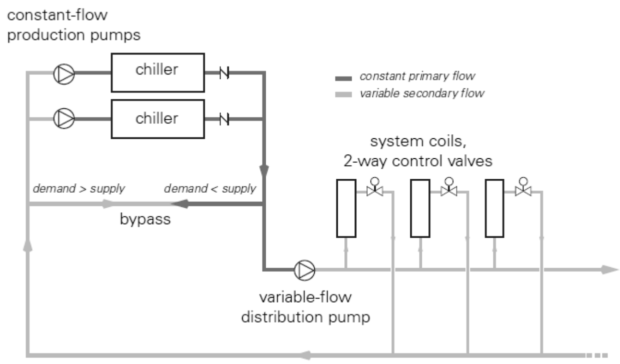

Figure 3: Decoupled chiller arrangement

In this cooling system using bypass line that connecting the production channel with constant flow rate pump type and distribution channel with variable flow rate pump type. The bypass line function is to balancing the large flow rate supplied and what is needed. On the operation, the flow rate of the production pump work with full load condition constantly, while distribution pumps working in variable at each operating coolant load[3].

c. The cooling system in dedicated

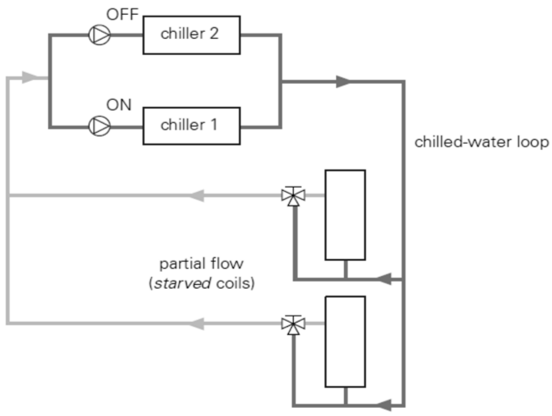

Figure 4: Dedicated chiller arrangement

In this cooling system, each chiller is connected to a production pump that works with variable flow rate. This

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variable flow rate works between the minimum and maximum limits of the chiller on the side of evaporator. By pass line that accompanied with modulation control valves is needed. This valves function is to maintain the minimum flow rate to the evaporator side of the cooling machine in order for the cooling machine is not experiencing surging [3].

RESEARCH METHODS

This study compares the design of water flow rates of AHRI standardization (air conditioning, heating and refrigeration institute) with low flow rate (low flow system) in office buildings. Each cooling capacity needs designed for 8438.4 kW with a conditioned area of 57,598 m2. Based on those needs are operated four chillers water cooled centrifugal types with a cooling capacity of 2109,6 kW each. In determining the type of chiller, TOPSS (Trane Official Product Selection System) software is needed to see the influence of the flow rate on the energy consumption, water pressure drop, and temperature on the evaporator side and condenser. Each of the chiller is compared into three different water cooled plant system, where the plant system consists of components: chiller, chilled water pumps, cooling water pumps and cooling towers. These components are designed to operate from Monday to Friday, at 07.00am-06.00pm. Determination of pump size based on the large of the water flow rate and water pressure drop with full load conditions. From each plant system, energy consumption measurements carried out for a year using software called Trace 700 chiller plant analyzer. The calculation result of the lowest total plant system energy consumption will determine the best flow rate type and plant system design.

RESULT AND DISCUSSION

The following cooling load profile for office type buildings based on the daily and monthly data generated using the Trace 700 Chiller Plant Analyzer software.

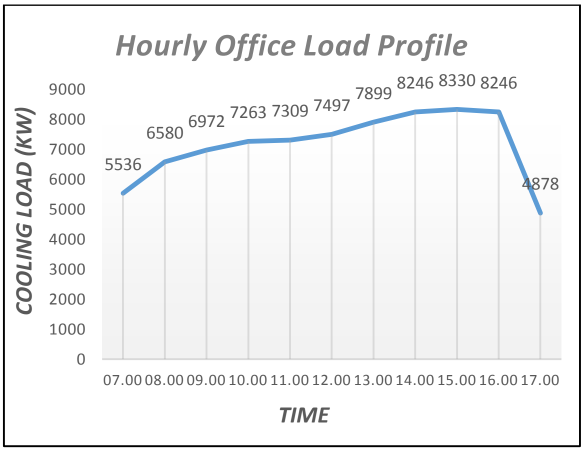

Figure 5: Hourly Office Load Profile

From the daily cooling load profile graph, it is visible that the relation between time and the cooling capacity increased from 07.00am until 03.00pm. This is due to the existence of the number of occupancy (human), lighting, office devices/equipment, infiltration and ventilation which is relatively constant accompanied by an increasingly high room temperature. The rise in temperature is due to solar radiation factors into the building structure and conduction to the roof, windows, floors, and interior partitions. Cooling peak load is at 03.00pm of 8330 kW. The reverse process occurred later than 03.00pm, the cooling load of the building experienced a decline.

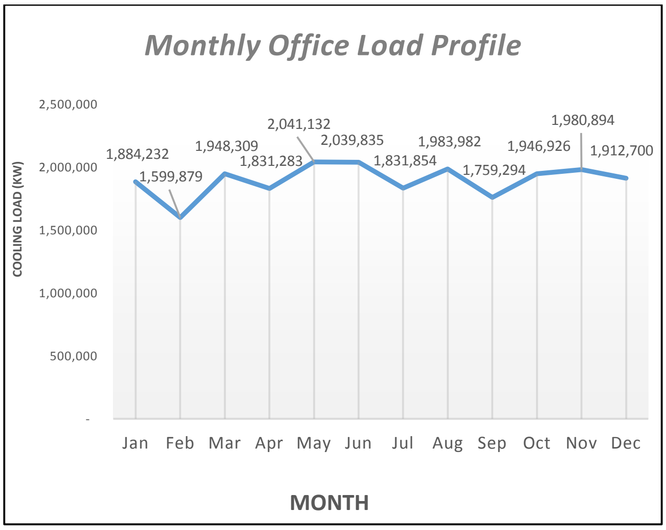

Figure 6: Monthly Office Load Profile

The cooling load profile above using weather data based on ASHRAE climatic data standards with outdoor air dry bulb/outdoor wet bulb temperature condition: 31.7'C/26.9'C (summer) and outdoor air dry bulb temperature 22.61'C (winter) for Jakarta, Indonesia location. The largest one-year cooling load was in May at 2,041,132 kW.

Furthermore, chiller selection is based on AHRI standardized flow rate and low flow system (low flow rate).

Table 1: Comparison of AHRI Chiller vs Low Flow

ITEM	AHRI STANDARD	Low Flow System
Chiller type	CVHG 565	CVHG 780
Cooling capacity (kW)	2109.6	2109.6
Power input (kW)	332.3	342.8
Evaporator		
- In/Out Temperature (C)	12.2/6.7	14/5
- Water flow rate (l/s)	91.32	55.81
- Pressure drop (kPa)	131.3	18.7
Condenser		
- In/Out Temperature (C)	29.4/34.6	29.5/37.8
- Water flow rate (l/s)	113.61	71.08
- Pressure drop (kPa)	52.9	20.9

Shows the relationship of the water flow rate to the type of chiller, power input, temperature difference and water pressure drop on the condenser side and evaporator chiller. From the table it can be concluded:

a. Chiller type:
   - AHRI : CVHG 565
   - Low Flow : CVHG 780

   Numbers 565 and 780, indicates the size of the compressor. Chiller with AHRI condition has a smaller compressor size than the low flow. This is because the AHRI chiller type is designed with the conditions of water temperature to the outside of the evaporator is higher than the low flow chiller type.

b. Chillers with AHRI standard require lower input power (332,3 kW) than the low flow chiller (342,8 kW). This is because:

   - AHRI design compressor type is smaller, that is CVHG 565

   - The temperature difference of AHRI on the chilled water side is lower than low flow system, that is 12.2’C – 6.7’C = 5.5’C

c. The water flow rate on the chilled water side and cooling water with AHRI standardization (91,32 1/s and 113,61 1/s) is higher compared to the low flow system (50,24 1/s and 71,07 1/s). This is because the chiller is designed with the same large cooling capacity (2109,6 kW), but experienced a temperature difference smaller on the side of the evaporator and the condenser. AHRI by 5.5’C and 5.2’C while low flow of 10’C and 8.3’C.

d. Water pressure drop on evaporator and condenser side at AHRI is higher, that is equal to 131,3 kPa and 52,9 kPa while the low flow is in 15,3 kPa and 20,9 kPa. The increasing of flow rates and water pressure drop will require bigger size of the chilled water pump and the cooling water pump.

   Once the chiller type is determined, the chiller is assembled into three different water-cooled plant systems.

Table 2: AHRI Energy Consumption

ENERGY CONSUMPTION PER YEAR (KW)-AHRI STANDARD				
MONTH	EQUIPMENT	Power Input (kW)		
		Parallel	Decoupled	Dedicated
Jan	Chiller	252,042.2	252,042.2	252,042.2
	Cooling tower	36,659.5	30,447.2	30,447.2
	Condenser pump	24,116.9	17,602.8	17,602.8
	Evaporator pump	130,946.6	100,284.3	95,624.7
Feb	Chiller	219,996.8	219,996.8	219,996.8
	Cooling tower	32,103.9	26,181.2	26,181.2
	Condenser pump	21,286.1	15,139.4	15,139.4
	Evaporator pump	115,575.9	85,018.4	82,241.2
Mar	Chiller	272,267.0	272,267.0	272,267.0
	Cooling tower	42,374.8	38,945.7	38,945.7
	Condenser pump	26,403.5	18,547.5	18,547.5
	Evaporator pump	143,361.4	106,882.8	100,755.1
Apr	Chiller	251,393.9	251,393.9	251,393.9
	Cooling tower	38,902.0	38,026.8	38,026.8
	Condenser pump	23,409.2	17,580.7	17,580.7
	Evaporator pump	127,104.1	101,383.8	95,503.9
May	Chiller	282,488.5	282,488.5	282,488.5
	Cooling tower	42,894.0	42,092.4	42,092.4
	Condenser pump	25,750.3	20,191.1	20,191.1
	Evaporator pump	139,814.5	115,097.1	109,684.4
Jun	Chiller	282,739.1	282,739.1	282,739.1
	Cooling tower	42,882.0	42,059.6	42,059.6
	Condenser pump	25,750.3	20,221.9	20,221.9
	Evaporator pump	139,814.5	115,185.1	109,851.7
Jul	Chiller	247,624.1	247,624.1	247,624.1
	Cooling tower	37,376.7	35,153.0	35,153.0
	Condenser pump	23,000.9	17,636.0	17,636.0
	Evaporator pump	124,887.1	99,437.1	95,804.3
Aug	Chiller	277,409.0	277,409.0	277,409.0
	Cooling tower	42,595.9	39,807.9	39,807.9
	Condenser pump	26,294.7	19,394.7	19,394.7
	Evaporator pump	142,770.2	109,955.1	105,357.8
Sep	Chiller	244,531.6	244,531.6	244,531.6
	Cooling tower	38,800.2	37,757.9	37,757.9
	Condenser pump	23,409.2	16,597.0	16,597.0
	Evaporator pump	127,104.1	97,268.8	90,159.5
Oct	Chiller	273,854.2	273,854.2	273,854.2
	Cooling tower	42,786.3	41,809.2	41,809.2
	Condenser pump	25,750.3	18,940.3	18,940.3
	Evaporator pump	139,814.5	109,873.5	102,888.8
Nov	Chiller	271,524.9	271,524.9	271,524.9
	Cooling tower	41,011.0	40,359.4	40,359.4
	Condenser pump	24,579.6	19,528.8	19,528.8
	Evaporator pump	133,459.1	110,889.2	106,087.0
Dec	Chiller	253,690.1	253,690.1	253,690.1
	Cooling tower	37,881.2	35,383.4	35,383.4
	Condenser pump	23,409.2	18,244.3	18,244.3
	Evaporator pump	127,104.1	103,885.8	99,108.1
	TOTAL	5,490,745.2	5,052,370.6	4,990,276.1

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Table 3: Low Flow Energy Consumption

ENERGY CONSUMPTION PER YEAR (KW)-LOW FLOW				
MONTH	EQUIPMENT	Power Input (kW)		
		Parallel	Decoupled	Dedicated
Jan	Chiller	272,085.9	272,085.9	272,085.9
	Cooling tower	14,758.0	6,990.2	6,990.2
	Condenser pump	13,560.4	9,957.1	9,957.1
	Evaporator pump	73,968.3	54,811.7	53,779.2
Feb	Chiller	238,943.2	238,943.2	238,943.2
	Cooling tower	12,884.1	5,969.0	5,969.0
	Condenser pump	11,968.7	8,555.1	8,555.1
	Evaporator pump	65,285.8	46,183.0	46,205.8
Mar	Chiller	295,090.3	295,090.3	295,090.3
	Cooling tower	16,396.7	8,658.3	8,658.3
	Condenser pump	14,846.0	10,436.0	10,436.0
	Evaporator pump	80,981.2	57,961.3	56,365.4
Apr	Chiller	266,236.5	266,236.5	266,236.5
	Cooling tower	15,551.6	9,671.8	9,671.8
	Condenser pump	13,162.7	9,997.0	9,997.0
	Evaporator pump	71,797.8	55,877.1	53,994.9
May	Chiller	295,252.6	295,252.6	295,252.6
	Cooling tower	17,393.1	11,110.5	11,110.5
	Condenser pump	14,478.9	11,504.7	11,504.7
	Evaporator pump	78,977.4	63,791.4	62,138.8
Jun	Chiller	296,324.3	296,324.3	296,324.3
	Cooling tower	17,299.1	11,059.5	11,059.5
	Condenser pump	14,815.6	11,458.2	11,458.2
	Evaporator pump	80,814.0	64,371.3	61,886.3
Jul	Chiller	262,776.2	262,776.2	262,776.2
	Cooling tower	14,821.1	8,481.7	8,481.7
	Condenser pump	12,933.1	9,995.3	9,995.3
	Evaporator pump	70,545.6	54,700.4	53,984.9
Aug	Chiller	298,132.5	298,132.5	298,132.5
	Cooling tower	16,757.9	9,290.8	9,290.8
	Condenser pump	14,784.8	10,989.9	10,989.9
	Evaporator pump	80,647.2	60,229.0	59,357.9
Sep	Chiller	262,732.9	262,732.9	262,732.9
	Cooling tower	15,325.3	9,284.6	9,284.6
	Condenser pump	13,162.7	9,400.3	9,400.3
	Evaporator pump	71,797.8	53,164.2	50,772.6
Oct	Chiller	291,472.4	291,472.4	291,472.4
	Cooling tower	17,052.1	10,540.9	10,540.9
	Condenser pump	14,478.9	10,744.5	10,744.5
	Evaporator pump	78,977.4	60,332.4	58,032.1
Nov	Chiller	281,943.0	281,943.0	281,943.0
	Cooling tower	16,702.0	10,772.0	10,772.0
	Condenser pump	13,820.6	11,220.0	11,220.0
	Evaporator pump	75,387.6	61,956.8	60,600.2
Dec	Chiller	267,360.7	267,360.7	267,360.7
	Cooling tower	14,863.7	8,513.9	8,513.9
	Condenser pump	13,162.7	10,352.60	10,352.60
	Evaporator pump	71,797.8	57,387.20	55,914.8
	TOTAL	4,584,308.2	4,254,070.2	4,236,337.3

From table two and three, there is a relation impact between three different water cooled plant system flow rates to energy consumption:

1. The chilled water side pumps

a. Parallel design

- AHRI : 1,591,756 kW
- Low flow : 900,978 kW

The low flow design is 43% more efficient compared to AHRI design

b. Decoupled design

- AHRI : 1,255,161 kW
- Low flow : 690,764 kW

The low flow design is 45% more efficient compared to AHRI design

c. Dedicated design

- AHRI : 1,193,067 kW
- Low flow : 673,033 kW

The low flow design is 44% more efficient compared to AHRI design

2. The cooling water side pumps

A. Parallel design

- AHRI : 293,160 kW
- Low flow : 165,175 kW

The low flow design is 43% more efficient compared to AHRI design.

B. Decoupled design

- AHRI : 219,624 kW
- Low flow : 124,611 kW

The low flow design is 43% more efficient compared to AHRI design.

C. Dedicated design

- AHRI : 219,624 kW
- Low flow : 124,611 kW

The low flow design is 43% more efficient compared to AHRI design.

3. Cooling tower

A. Parallel design

- AHRI : 476,267 kW
- Low flow : 189,805 kW

The low flow design is 60% more efficient compared to AHRI design.

B. Decoupled design

- AHRI : 448,024 kW

- Low flow : 110,343 kW

The low flow design is 75% more efficient compared to AHRI design.

C. Dedicated design

- AHRI : 448,024 kW

- Low flow : 110,343 kW

The low flow design is 75% more efficient compared to AHRI design.

4. Chiller

Parallel, decoupled, dedicated design are same

- AHRI : 3,129,562 kW

- Low flow : 3,328,350 kW

The AHRI flow rate design is 6% more efficient compared to low flow design.

5. Total energy consumption per system for one year

A. Parallel design

- AHRI : 5,490,745.2 kW

- Low flow : 4,584,308.2 kW

The low flow design is 17% more efficient compared to AHRI design.

B. Decoupled design

- AHRI : 5,052,370.6 kW

- Low flow : 4,254,070.2 kW

The low flow design is 16% more efficient compared to AHRI design.

C. Dedicated design

- AHRI : 4,990,276.1 kW

- Low flow : 4,236,337.3 kW

The low flow design is 15% more efficient compared to AHRI design.

From the above comparison results, the largest total energy consumption caused by chiller with an average percentage above 60%. Flow rate with AHRI design has an advantage on the chiller side with energy consumption savings of 6%, but on the side of the pump and cooling tower is no better than the low flow design. The savings in the chiller are due to the higher temperature design and the temperature difference of water out on the chilled water side is not large. Water temperature on the chilled water side is only 6.7’C and the temperature difference is 5.5’C. The low temperature setting point causes the cooling capacity of the chiller to drop. To pursue the cooling capacity, the low flow compressor type rises to CVHG 780 so that the power input is bigger.

Energy consumption of the pump and the cooling towers at low flow is lower in each system. In the pump unit, things that affect energy consumption lies in the amount of flow rate and water pressure drop. The value of flow rate-water pressure drop on the chilled water side and low flow cooling water are 0.0265 L/s/kW-121.9 meters water and 0.0337 L/s/kW-17.3 meters water, while AHRI 0.0433 L/s/kW-133.39 meters water and 0.0538 L/s/kW-20.4 meters water.

For cooling towers, factors affecting energy consumption are: the out water temperature from the cooling tower, the flow rate, the wet bulb temperature of the environment, and its cooling capacity. Amount of the cooling capacity, wet bulb temperature and the out water temperature from the cooling towers are the same, both for low flow design and AHRI. What distinguishes is the flow rate of the water. AHRI flow rate in the amount of 113.61 L/s, while the low flow in the amount of 71.08 L/s. To move the heat from the water to the environment used the motor fan on the cooling tower. The water flow rate is directly proportional to the size of the motor fan. The fan motor size is proportional to the energy consumption required.

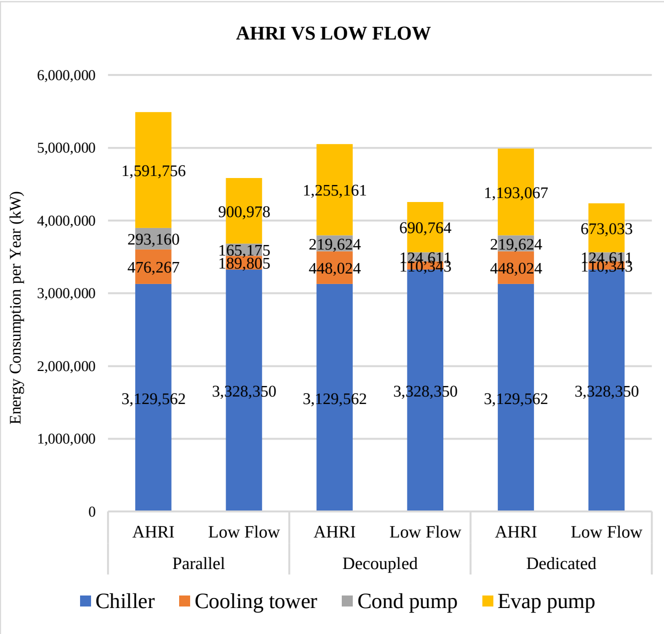

Figure 7: Total Energy Consumption of AHRI vs Low Flow

Based on the graph above, the big difference in energy consumption between the three of water cooled systems lies in: the number of pumps is directly proportional to the energy consumption. The type of water flow rate is divided into two, namely the variable and constant in each operating load condition.

In a parallel system, it has four chilled water pumps and four cooling water pumps. In total the amount of pump energy consumption calculated in the system is eight pumps with a constant type of water flow rate at each operating load.

In a decoupled system, it has eight chilled water pumps (four production pumps and four distribution pumps) and four cooling water pumps. In total the amount of the calculated energy consumption in this system as many as twelve pumps. Four production pumps are designed with a constant flow rate type, while the four distribution pumps and four cooling water pumps are designed with a variable water flow rates at each operating load.

In a dedicated system, it has eight pumps (four cold water pumps and four cooling water pumps) with variable water flow rate type according to its operating load.

Energy consumption with the type of constant water flow rate pump at each operating point always works at the cusp. Unlike the type of pump with variable water flow rate. Therefore, energy consumption with the constant flow rate-pump type tends to be higher compared to the variable flow rate pump type. Following are the pump energy consumption curve compared with its operating capacity:

a. The type of constant water flow pump

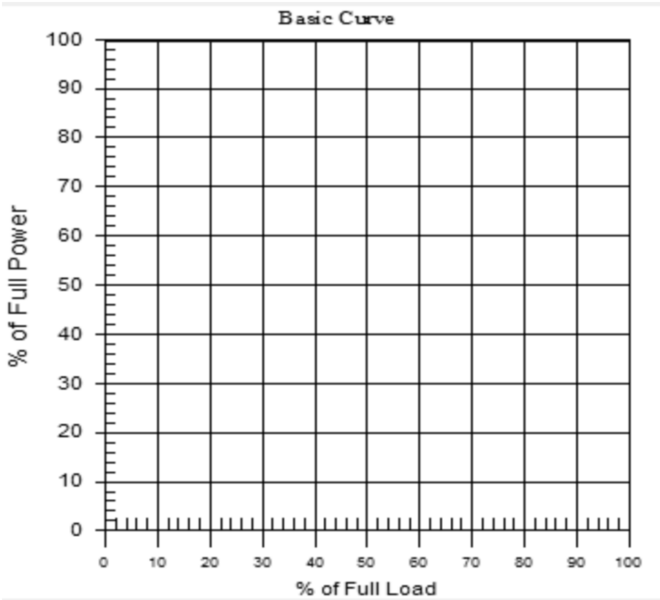

Figure 8: Constant Flow Rate Pump Curve

b. The type of variable water flow pump

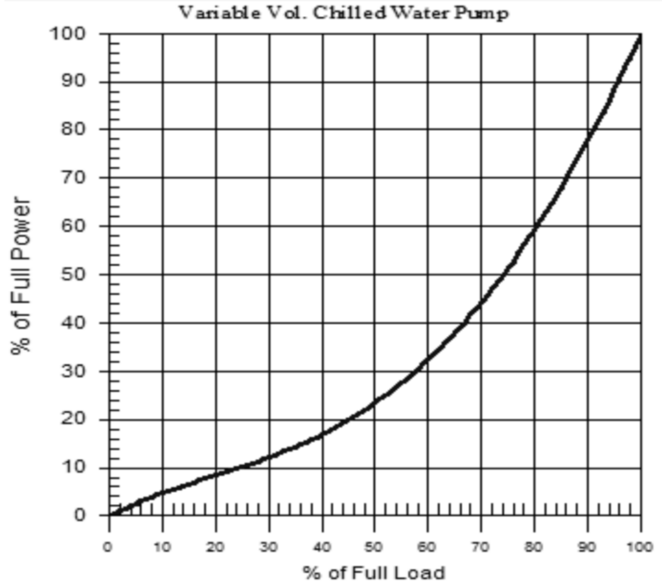

Figure 9: Variable Flow Rate Pump Curve

CONCLUSION

From the results of the data processing, calculations, graph analysis, and discussion obtained a conclusion that the energy consumption of low flow design by using the dedicated system is the lowest with total value of energy consumption per year of 4,236,337.3 kW. If the operational cost is calculated (USD 0.10873/kWH) for a year with AHRI standard flow rate with dedicated system (4.990.276 kW), the obtained results in saving is USD 81,972.69.

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