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A Feasibility Study on Energy Saving through Reclaiming Excess Condensed Water into Cooling Tower Circulation

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Abstract

This paper investigates the potential of energy saving on cooling tower system by utilizing the condensate from Air Handling Units (AHUs). The proposed condensation system is to channel the condensate into the inlet condenser pipeline which is connected to the top of cooling towers. Mixing the condensate with higher condenser water temperature lowering the inlet cooling tower water temperature from its set value of 35˚C to 32.9˚C. Merkel Theory is used to determine the tower characteristic of the new inlet condenser water temperature through analysis of enthalpies and temperatures of air and water. The value of 0.836 is obtained and proven to be within design range of cooling tower characteristics curves. Lowering the inlet condenser water temperature to 32.9^{0}C means that less energy is required to cool the outlet cooling tower water temperature to 30^{0}C, therefore reducing the speed of cooling tower fan, hence reducing the fan power consumption. Based on the theoretical calculation, the energy saving of one cooling tower (3-cell) by utilizing the proposed condensate system is 688.94 kW monthly, an increase of 80.5 % from the existing system which indirectly contributing to lower carbon emission to environment. A conceptual model on utilization of condensate from AHUs into cooling tower system is design to provide better view and guidance for future references.

Keywords: Condensate System Recovery; Cooling Tower Analysis; Specific Enthalpy of Air and Water; Energy Saving

INTRODUCTION

Energy consumption has been a long-standing issue for most of the buildings around the world. It is found that buildings consume about 40% of total world energy [1]. HVAC systems contribute to the highest percentage especially for office buildings and shopping centers. There are on-going research and case studies that focused on minimizing energy consumption in commercial buildings [2], [3]. Licina (2012) re-emphasize that HVAC systems in facilities such as hospitals, laboratories as well as shopping mall can consume five to ten times more energy compared to typical office building. This higher energy use is due to many factors including provision of large amounts of 100% outside air, continuous operation, requirement for stringent internal parameters, high fan energy and many more [4] .

Due to the increase in water rates, condensate recovery systems are very cost-effective investment. The practice of using condensate from air conditioning systems as a source of water has drawn attention from researcher as well as businessman[5], [6]. Condensate is often viewed as waste product that channels to drainage lines. The volume of condensate produced cannot be underestimated especially from air conditioning systems of commercial buildings. According to Guz (2005), a downtown mall in San Antonio generated 250 gallons (946 L) each day from its AHUs [7]. The downtown River center Mall collects 946 l of condensate per day, which is used to partially offset cooling tower water losses. It is found that the fastest payback period for condensate recovery system is utilizing the water for cooling tower make up, which can be less than a year. Licina (2012) in her study on hot and humid climate find out that it is possible to provide over 50% reduction in portable water necessary for cooling tower make-up and to increase cooling tower efficiency due to the introduction of a water source that has virtually no hardness with a very low content of total dissolved solids [4]. Even though this study is utilizing the condensate to cooling tower system but it is focusing on the make-up water not inside the cooling tower circulation itself.

K.Loveless (2012) in his study on quality impact of condensate water collection identified that the quality of condensate water collected from various locations in Arabian Peninsula, Sub-Saharan Africa and South Asia was close to distilled water and, with low-cost polishing treatments, such as ion exchange resins and electrochemical processes, the condensate quality could easily reach that of potable water [8]. In terms of the critically of condensate water quality, the authors have put an assumption not to include any contamination study into this research since it is found to have less impact to the system.

This research focused on the ability of condensate from AHUs on providing energy saving for cooling tower. The condensate from AHUs is mixed into cooling tower water circulation and finally lowering the inlet temperature of cooling tower circulation which contribute to energy saving opportunity. Data collection of volume and temperature of condensate are collected from selected AHUs only. In this research, the contamination of condensate and cost evaluation of the condensate system are not taken into consideration. Based on literature review, there are no recent research with similar intention yet since it is quite unrealistic to reflect the change in existing building due to the high cost effect. However, new building development should have high potential in embedding the proposed concept. This feasibility study will be extended to a more detail analysis and consideration in future by collaborating with civil engineers as well as experts in building and HVAC system.

METHODOLOGY

A conceptual model on utilization of condensate from AHUs into cooling tower water circulation is developed as shown in Figure 1. This model is applied in this research as discussed in section 3 onwards. This conceptual model can also be applied to most of the commercial HVAC system.

This research is conducted at Plaza Alam Sentral, Shah Alam, Malaysia. The HVAC system in this building contained of 6 units of water-cooled chiller system, 6 units of cooling tower and 36 AHUs. There are only 13 AHUs chosen to be investigated further after a series of inspection and evaluation on all the operating AHUs, due to higher volume of condensate produced from these 13 AHUs. The volume flow rate and temperature of the condensate from 13 AHUs are collected for further analysis.

The cooling towers of Plaza Alam Sentral operate along with chillers for 15 hours per day from 7a.m. to 10p.m. Plaza Alam Sentral has three units of 3-Cell cooling towers operating, which means that 9 units of cooling tower fans are running at full speed all the time. According to cooling tower design in Table 1, cooling tower fans are operating at the speed of 374 RPM in order to cool hot temperature of 35ºC to 30ºC at 27ºC of ambient wet bulb temperature, where heat load of 3175 kW is rejected.

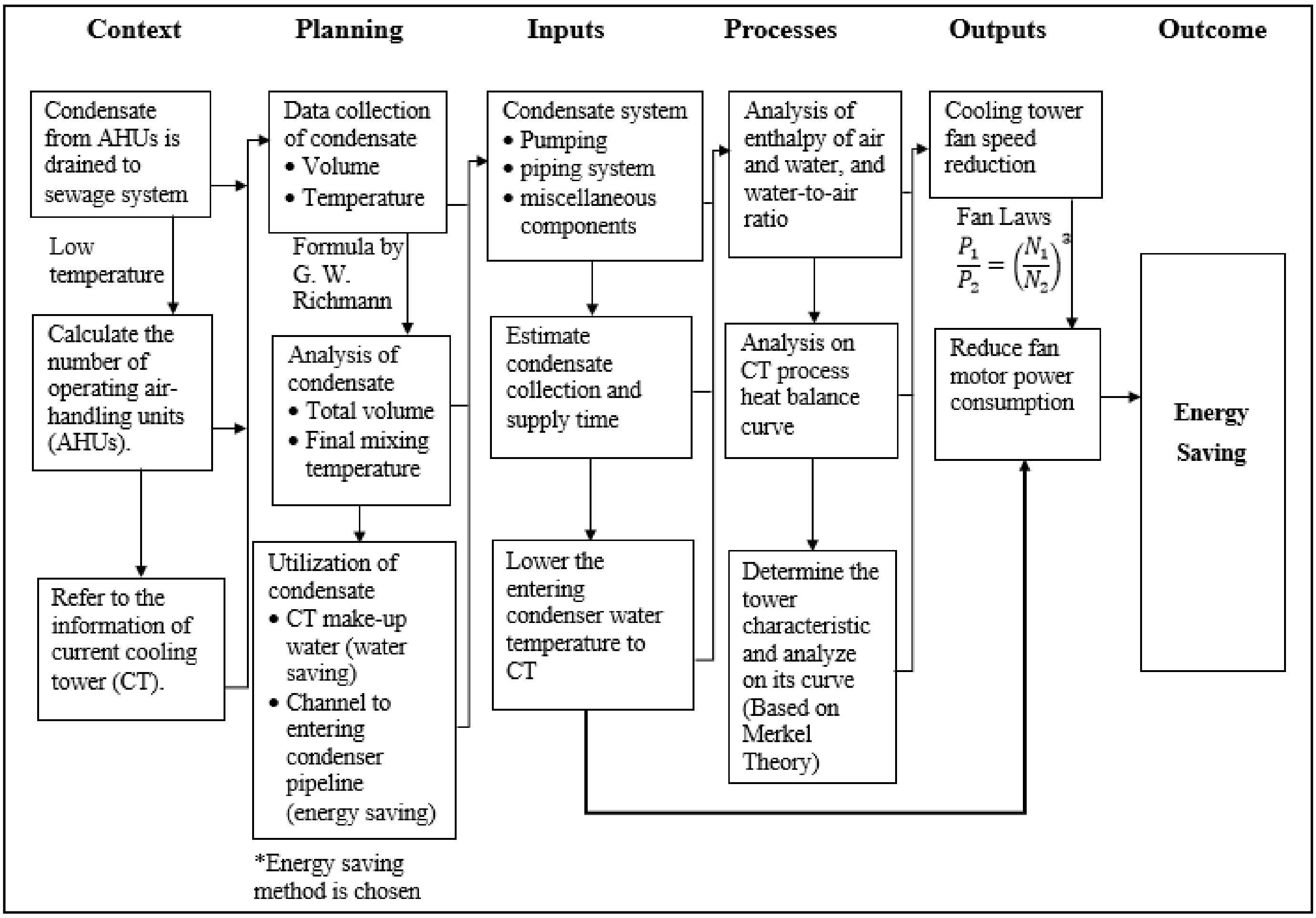


Figure 1: Conceptual model on utilization of condensate from AHUs into cooling tower water circulation

Table 1: Plaza Alam Sentral Cooling Tower Characteristics

Cooling Tower Characteristics	**Description**
Quantity	6 units (3-Cell each), 3 units operating
Cooling Capacity	750 kW
Fan Type	Axial Flow
Fan Speed	3 Speed (374 RPM at Max Power)
Fan Drive	V-belt & Pulley
Fan Motor Rated Output	3 x 7.5 kW

ANALYSIS OF THE CONDENSATE

Recovery of Condensate from AHUs

In order to collect the data of condensate, series of data collection is executed and finally only 13 units of AHUs are chosen across the mall since they produced higher volume compared to others. Several attempts were performed on all AHUs to achieve better data accuracy using equipment such as volume measuring tool and thermometer. The condensate is collected in 10 seconds, while the volume and temperature is determined after the collection. Result of volume flow rate and temperature of condensate for the best two attempts are recorded in Table 2, resulted to total amount of 6939.27 L condensate per day produced by 13 AHUs. It means that more than 6939.27 L of water source is channel to drain without further usage in one day for a total of 36 AHUs in the building. So, the huge amount of condensate should be used for better purpose.

Total volume of condensate recovered from 13 AHUs in a day
= 0.009885 ml/day x 60 s x 60 mins x 15 hours × 13 units

= 6939.27 L/day

Table 2: Summary of condensate recovered from AHUs

Level	Lift Lobby	Volume Flow rate of Condensate (ml/10s)		Average Volume Flow Rate of Condensate (ml/10s)	Average Temperature (℃)
		Attempt 1	Attempt 2		
5	4	165	170	167.5	12.2
4	1	100	90	95	14.1
	3	130	150	140	11.4
3	2	85	100	92.5	17.1
	3	140	135	137.5	14.1
2	1	40	50	45	16.7
	4	85	90	87.5	13.0
1	1	40	35	37.5	18.0
	2	95	105	100	13.7
Ground	2	120	115	117.5	16.0
	4	40	45	42.5	19.0
Lower Ground	2	120	115	117.5	13.8
	3	110	100	105	13.7
	Average Flow Rate of Condensate			98.85 (ml/10s)	

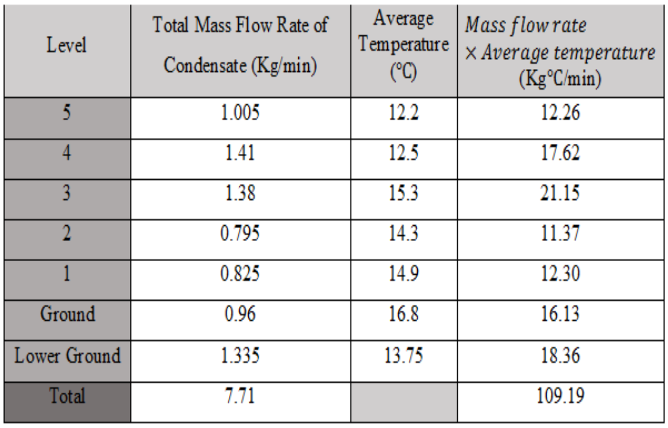
Analysis of mixing flow temperature

Condensate are collected from all the selected AHUs and transferred to water storage tank before channeling to cooling tower water circulation. Condensate are mixed in terms of different volume and temperature from AHUs, therefore analysis on the mixture of temperature is really important in order to obtain the final temperature in the storage tank. As illustrated in Equation 1, the final temperature of water mixture depends on the masses or volumes of one or more amounts of water mixture and their initial temperatures.

$$T_{final} = \frac{m_1T_1+m_2T_2+\cdots}{m_1+m_2+\cdots} \qquad \text{-------------- (1)}$$

The volumes and temperatures of condensate from 13 AHUs have been collected from lower ground to fifth floor. In order to increase the accuracy of temperature mixture of the condensate, analysis on final temperature is performed on each floor prior to the analysis of combined total condensate from 13 AHUs. The analysis of temperature mixture is based on the volume of condensate collected in one minute.

Table 3: Summary of condensate recovered from AHUs of every floor



Level	Total Mass Flow Rate of Condensate (Kg/min)	Average Temperature (°C)	*Mass flow rate × Average temperature* (Kg°C/min)
5	1.005	12.2	12.26
4	1.41	12.5	17.62
3	1.38	15.3	21.15
2	0.795	14.3	11.37
1	0.825	14.9	12.30
Ground	0.96	16.8	16.13
Lower Ground	1.335	13.75	18.36
Total	7.71		109.19

The final temperature of 14.2 C is calculated by using Equation 1 based on the tabulated data in Table 3. This final temperature is used for further analysis especially in designing phase of reclaimed condensate system.

Condensate system design

The designated condensate system is used to channel the condensate from AHUs for the use of cooling tower water circulation. After considering the critical gain on inlet and outlet flow of condenser water from chiller system, the design system as illustrated in Figure 2 is chosen as final design.

This system supplies condensate from water storage tank to the pipeline of condenser water flow to cooling tower. The pipeline of the system is connected to the pipeline of outlet condenser water from chiller system, which resulting in decreasing of condenser water temperature before entering cooling tower. The process involves the mix flow of two different fluids. Therefore further analysis is performed especially on the volume and temperature mixture. The disadvantage of this design is the heat absorb to the cold condensate due to the application of water storage tank. This will reduce the effectiveness of the temperature mixture of condensate and condenser water.

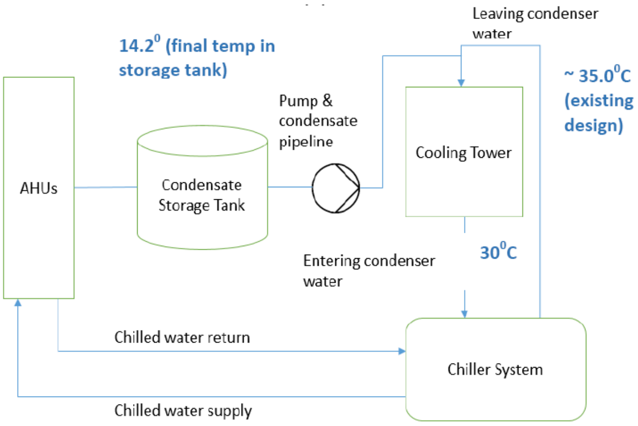


Figure 2: Alternative Design

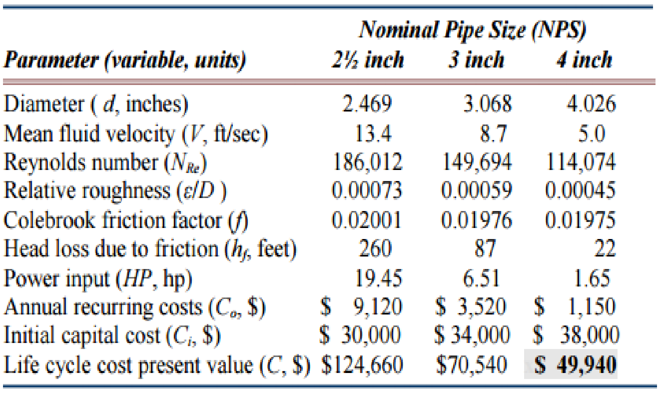
Due to the unpredictable production of condensate from AHUs, it is very difficult to set the collection and supplying time for the condensate. Therefore, for simplicity, it is proposed that the condensate is collected for 30 to 45 minutes to obtain approximate volume of 231.3L which stored in a small storage tank. Then, the condensate is pumped for 5 to 10 minutes directly to the condenser pipeline. The process is repeated throughout the operation of cooling tower. The miscellaneous components of the condensate system such as valve, timer, pump, pipe and others are not taken into consideration, assuming that the system works perfectly.

The water quality of condensate is not part of this research. However, the condensate produced from AHUs is somehow similar to distilled water, which has a slightly acidic pH value at the range of 5.6 to 6.0 and contains no mineral [9]. The condensate is subject to environmental contamination during the collection process and transport, for example microorganisms. So, it is assumed that the water quality of condensate will not bring any negative effect when mixing with the condenser water into cooling tower circulation.

Analysis of Mixture of Condensate and Condenser Water

All the AHUs are connected to 8 inch pipes that flow direct to sewer, there are different length of pipes used for different location of AHUs in AHU room, for example two AHUs in a AHU room required different length of pipes in order to channel condensate to sewer system. Mixing condensate and condenser water will result in temperature change of outlet condenser water before entering cooling tower, for this case it lowers the temperature. From the cooling tower manual of Plaza Alam Sentral, the cooling tower is designed at outlet condenser water temperature of 35ºC and flow rate of $106L/s$. By utilizing condensate system design in figure 2, the 35ºC of condenser water temperature can be lowered down to certain value through proper calculation and selection of piping system.

Table 4: Summary of Economic Variables of Three Alternative Pipe System [10]



Parameter (variable, units)	*Nominal Pipe Size (NPS)* *2½ inch*	 *3 inch*	 *4 inch*
Diameter (d, inches)	2.469	3.068	4.026
Mean fluid velocity (V, ft/sec)	13.4	8.7	5.0
Reynolds number (N_{Re})	186,012	149,694	114,074
Relative roughness (ε/D)	0.00073	0.00059	0.00045
Colebrook friction factor (f)	0.02001	0.01976	0.01975
Head loss due to friction (h_f, feet)	260	87	22
Power input (HP, hp)	19.45	6.51	1.65
Annual recurring costs (C_o, \$)	\$ 9,120	\$ 3,520	\$ 1,150
Initial capital cost (C_i, \$)	\$ 30,000	\$ 34,000	\$ 38,000
Life cycle cost present value (C, \$)	\$124,660	\$70,540	**\$ 49,940**

From the table above, nominal pipe size of 4 inch is chosen for the condensate system. The reason of choosing 4 inch diameter pipe is because the condenser pipelines use the diameter of 8 inch, therefore 4 inch pipe connects to 8 inch pipe would be most suitable. The 4 inch diameter pipe has the mean fluid velocity of approximately 1.5 m/s, which means that the condensate flow rate is 1.5m/s in 4 inch pipe. Flow rate to condensate flowing inside the 4 inch pipe is 12.161 L/s by using Equation 2.

$$Q = \frac{1}{4} \cdot \pi \cdot D^2 \cdot V \qquad \text{----- (2)}$$

Where D = diameter of pipe (m)

V = velocity of fluid (m/s)

The value of flow rate is then used to calculate the final temperature of outlet condenser water temperature using Equation 1 which is 32.9℃. This final temperature of 32.9℃ from the mixture of condensate and condenser water is instantaneous temperature for certain period of time. As discussed above, the condensate produced is insufficient to supply continuously to the cooling tower circulation. When condensate is collected for 30 to 45 minutes in storage tank and pump to outlet condenser pipeline for 5 to 10 minutes, assuming minimal loss and perfect insulation of pipeline, the value of outlet condenser water temperature obtained would be 32.9℃ before entering the cooling tower.

COOLING TOWER PERFORMANCE ANALYSIS

The theoretical calculation (Equation 3 – 12) for Analysis of Specific Enthalpy of Air and Water as well as Cooling tower Characteristic analysis and (Figures 3-4) in this section is referred to Herbert W. Stanford III (2011) [10].

Analysis of Specific Enthalpy of Air and Water

The process of a counter-flow cooling tower is represented graphically in Figure 3. Outlet condenser water entering from the top of cooling tower at $T_{w,i}$, is surrounded by film that is assumed to be saturated with water vapor at wet-bulb temperature, this can be seen in the figure at point A on water operating line. The water is then cooled to $T_{w,o}$ where the film enthalpy follows the water operating line to point B. The air operating line begins at point C, where point B is vertically above it. The difference between point C and B is also known as enthalpy driving force $(h' - h)$ of a cooling tower. Enthalpy of air increases along the straight line CD as inlet air absorbed the heat from hot water. The ratio of water-to-air (L/G) is the slope of air operating line CD, for cooling tower, the value of L/G is obtained from the ratio of total mass flow rate of water and dry air. If L/G increases, air operating line will be approaching to the water operating line. The maximum L/G and minimum air flow occur when the average wet bulb temperature of air leaving the cooling tower equals to inlet water temperature. The maximum value of L/G is obtained when the slope of line is connected from point C to A.

The new calculated value of inlet cooling tower water temperature can be used to determine the value of Merkel Number (Me_M) of the cooling tower, the process of getting the value involving a series of calculations to first determine the specific enthalpy of saturated air at inlet and outlet water temperature, specific enthalpy of inlet and outlet air, and outlet air temperature.

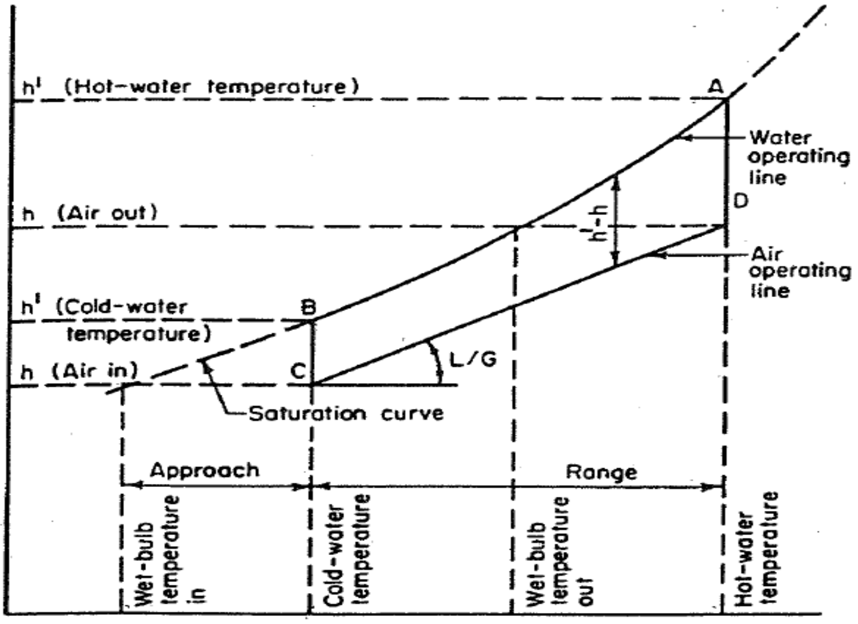


Figure 3: Cooling tower process heat balance

Table 5: Information for air and water of cooling tower.

Description	**Data**
Inlet air condition, $t_{air,i}$ (Average per year)	30℃ & Relative Humidity, $\varphi = 75\%$
Atmospheric pressure, P	101.325 kPa
Inlet water temperature, $t_{w,i}$	32.9 ℃ ≈ $306.05K$
Outlet water temperature, $t_{w,o}$	30 ℃ ≈ $303.15K$
Specific heat capacity of water, C_{pw}	4.18 $kJ/kg \cdot K$
Specific heat capacity of air, C_{pa}	1.005 $kJ/kg \cdot K$
Latent heat of vaporization of water, h_{fg}	2257 kJ/kg

Saturated water vapor pressure of air at temperature of t_{air}, $\boldsymbol{P_{air}}$ is calculated as follows:

$$\begin{cases} \boldsymbol{P_{air}} = 98.066\boldsymbol{B} \\ \mathbf{log}\,\boldsymbol{B} = 0.0141966 - 3142.305(\frac{1}{T_{air}} - \frac{1}{373.16}) + 8.2\log\left(\frac{373.16}{T_{air}}\right) - 0.0024804(373.16 - T_{air}) - - - (3) \\ \boldsymbol{T_{air}} = t_{air} + 273.15 \end{cases}$$

$$\boldsymbol{T_{air}} = 30 + 273.15 = 303.15K$$

$$\boldsymbol{B} = 0.0411611$$

$$\boldsymbol{P_{air}} = 98.066(0.0411611) = \mathbf{4.0365\ kP}$$

Ratio of water –to-air $(^{L}/_{G})$ can be calculated as follows:

$$\frac{\boldsymbol{L}}{\boldsymbol{G}} = \frac{C_{pa}}{C_{pw}} + \frac{h_{fg} \times 0.622 \times e^{18.6 - \frac{5206.9}{t_{w,i}}} \times 5206.9 \times P}{C_{pw} \times {t_{w,i}}^2 \times \left[P - e^{18.6 - \frac{5206.9}{t_{w,i}}}\right]^2} - - - (4)$$

$$\frac{\boldsymbol{L}}{\boldsymbol{G}} = \frac{1.005}{4.18} + \frac{(2257) \times 0.622 \times e^{18.6 - \frac{5206.9}{306.05}} \times 5206.9 \times 101.325}{4.18 \times (32.9 + 273.15)^2 \times \left[101.325 - e^{18.6 - \frac{5206.9}{306.05}}\right]^2}$$

$$\frac{\boldsymbol{L}}{\boldsymbol{G}} = 1.2356$$

Specific enthalpy of saturated air at inlet water temperature, $t_{w,i}$ is calculated as follows:

$$\boldsymbol{h_{sa,i}} = 1.005t_{w,i} + \frac{0.622P_{air}}{P - P_{air}}(2500.8 + 1.842t_{w,i}) - - - (5)$$

$$= 1.005(32.9) + \frac{0.622(4.0356)}{101.325 - 4.0356}(2500.8 + 1.842(32.9)$$

$$= \mathbf{99.166}\ ^{\boldsymbol{kJ}}/_{\boldsymbol{kg}}$$

Specific enthalpy of saturated air at outlet water temperature, $t_{w,o}$ is calculated as follows:

$$\boldsymbol{h_{sa,o}} = 1.005t_{w,i} + \frac{0.622P_{air}}{P - P_{air}}(2500.8 + 1.842t_{w,i}) - - - (6)$$

$$= 1.005(30) + \frac{0.622(4.0356)}{101.325 - 4.0356}(2500.8 + 1.842(30)$$

$$= \mathbf{96.1137}\ ^{\boldsymbol{kJ}}/_{\boldsymbol{kg}}$$

Mean specific enthalpy of saturated air at inlet and outlet water temperature is calculated as follows:

$$\boldsymbol{h_{sam}} = \frac{h_{sa,i} + h_{sa,o}}{2} \qquad - - - (7)$$

$$= \frac{99.166 + 96.1137}{2}$$

$$= \mathbf{97.6399}\, {}^{\boldsymbol{kJ}}\!/_{\boldsymbol{kg}}$$

Specific enthalpy of inlet air of at the bottom of cooling tower is calculated as follows:

$$\boldsymbol{h_{a,i}} = 1.005t_{db} + \frac{0.622\varphi P_{air}}{P - \varphi P_{air}}(2500.8 + 1.842t_{db}) - - - (8)$$

$$= 1.005(30) + \frac{0.622(0.75)(4.0365)}{101.325-(0.75)(4.0365)}(2500.8 + 1.842(30))$$

$$= \mathbf{81.6195}\, {}^{\boldsymbol{kJ}}\!/_{\boldsymbol{kg}}$$

Specific enthalpy of outlet air at the top of cooling tower is calculated as follows:

$$\boldsymbol{h_{a,o}} = h_{a,i} + C_{pw}\Delta t\left({}^{L}\!/_{G}\right) \qquad - - - (9)$$

$$= 81.6195 + (4.18)(32.9 - 30)(1.2346)$$

$$= \mathbf{96.5853}\, {}^{\boldsymbol{kJ}}\!/_{\boldsymbol{kg}}$$

Outlet air temperature is calculated as follows:

$$\boldsymbol{t_{air,o}} = t_{air,i} + \left(\frac{t_1 + t_2}{2} - t_{air,i}\right)\left(\frac{h_{a,o} - h_{a,i}}{h_{sam} - h_{a,i}}\right) - - - (10)$$

$$= 30 + \left(\frac{32.9 + 30}{2} - 30\right)\left(\frac{94.0807 - 81.6195}{97.6399 - 81.6195}\right)$$

$$= \mathbf{31.13}℃$$

Cooling tower Characteristic analysis

Analysis on the performance of cooling tower after utilizing condensate system is based on Merkel Theory. In 1925, Merkel [10] first proposed a theory on evaporation and heat transfer of water and air, particularly for counter-flow cooling tower. Briefly after the theory introduced by Merkel, researchers such as [11] have since developed basic equation for cooling tower performance calculation as well as the introduction of number of transfer unit (NTU) to evaluate cooling tower operation condition. From that, NTU or Merkel Number or tower characteristic is determined from the analysis of enthalpy of air and water of cooling tower using equations developed by researchers stated above.

There are three key assumptions made by Merkel [4]. First, the resistance for heat transfer in the water film is negligible. Second, the air leaving cooling tower after cooling process is saturated with water vapor (100% relative humidity), allowing calculations only for temperature and specific enthalpy. Third, the effect of water loss and mass of evaporated water vapor are negligible, which allows the energy transfer is assumed at water temperature range. The integrated value or KaV/L is known as tower characteristic that relates to the amount of energy transferred according to tower design and operating characteristics. In other words, it indicates the performance demand or degree of difficulty to cool the water of a tower.

The combinations of mass and energy transfer equations and the assumptions made above, result in the Merkel equation:

$$NTU = Me_M = \frac{KaV}{L} = \int_{t_{w,o}}^{t_{w,i}} \frac{C_{pw}\, dT}{h_{sa} - h_a} \quad - (11)$$

Where K = mass transfer coefficient ($kg/m^2 \cdot s$);

a = Area of contact between air and water (m^{-1});

V = active cooling volume (m^3);

L = mass flow rate of inlet water (kg/s);

$t_{w,i}$ = inlet water temperature (K);

$t_{w,o}$ = outlet water temperature (K);

C_{pw} = specific heat capacity of water ($kJ/kg \cdot K$);

h_{sa} = enthalpy of saturated air at local water temperature (kJ/kg);

h_a = enthalpy of local air stream (kJ/kg);

The new calculated value of inlet cooling tower water temperature is used to determine the value of Merkel Number (Me_M) of the cooling tower, the process of getting the value involving a series of calculations to first determine the specific enthalpy of saturated air at inlet and outlet water temperature, specific enthalpy of inlet and outlet air, and outlet air temperature. Table 6 summarize the required information.

Figure 4 represents a typical graph for choosing a suitable cooling tower, usually provided by manufacturer to customers. The straight line shown in the figure is a plot of KaV/L vs L/G at constant airflow. According to the graph, the design condition of a cooling tower is capable of cooling the water to a temperature that is 10°F above the wet bulb temperature. The values of 0.836 of KaV/L and 1.2356 of L/G from Section 4.1 are within the design range according to the graph. The cooling tower of Plaza Alam Sentral has its own designed tower characteristics, however, the new calculated value KaV/L proved that the tower is capable of operating under the new inlet water temperature. So, further analysis is focusing on the energy saving in cooling tower

Table 6: Information for air and water of cooling tower.

Description	**Data**
Inlet air condition, $t_{air,i}$ (Average per year)	30℃ & Relative Humidity, $\varphi = 75\%$
Atmospheric pressure, P	101.325 kPa
Inlet water temperature, $t_{w,i}$	32.9 ℃ ≈ 306.05K ***(latest design)***
Outlet water temperature, $t_{w,o}$	30 ℃ ≈ 303.15K
Specific heat capacity of water, C_{pw}	4.18 $kJ/kg \cdot K$
Specific heat capacity of air, C_{pa}	1.005 $kJ/kg \cdot K$
Latent heat of vaporization of water, h_{fg}	2257 kJ/kg

$$\boldsymbol{NTU = Me_M = \frac{KaV}{L}} = \int_{t_{w,o}}^{t_{w,i}} \frac{C_{pw}\, dT}{h_{sa} - h_a} --- (12)$$

$$= \frac{4.18(32.9 - 30)}{96.1137 - 81.6195}$$

$$= \mathbf{0.836}$$

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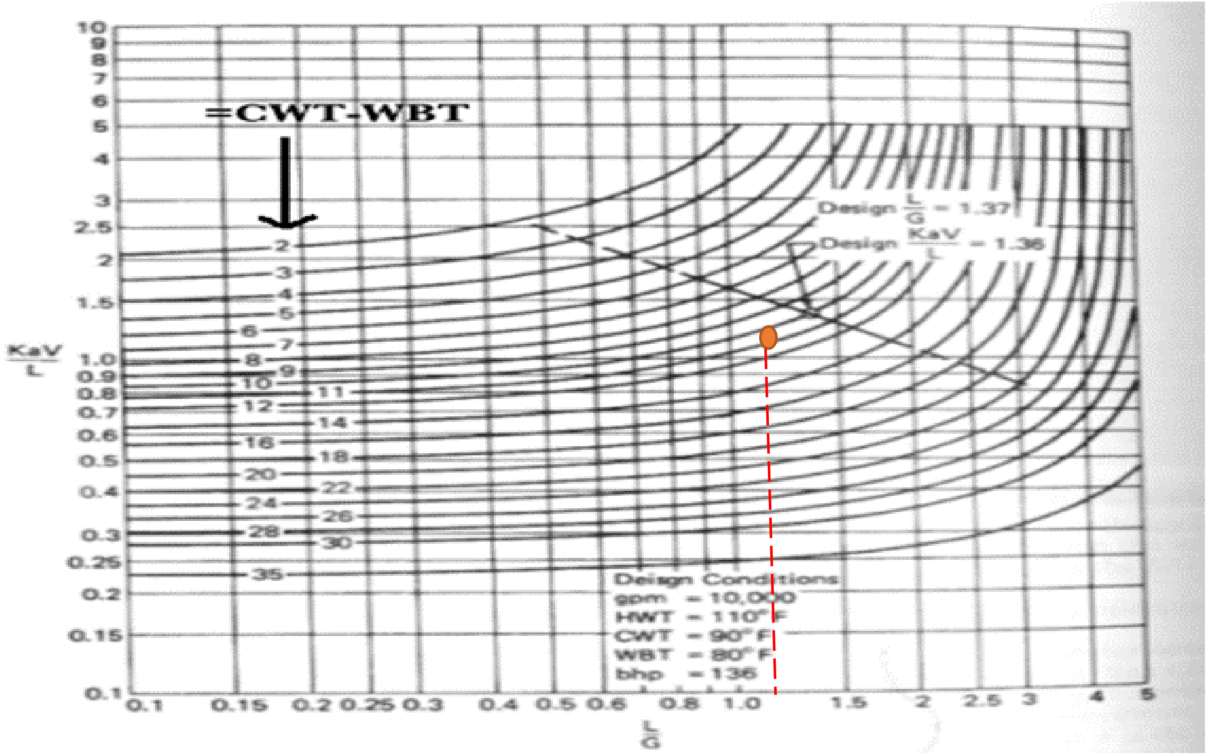


Figure 4: A typical set of tower characteristic curves

Energy Saving analysis

By utilizing the proposed condensate system, the inlet condenser water temperature is reduced from 35℃ to 32.9℃ for a short period of time and is used to analyze the opportunity of energy saving by reducing the speed of cooling tower fans. According to Fan Laws, reducing the speed of fans decreases the power input of fan motors. The cooling tower fans do not have to run at full speed as the inlet condenser water temperature is decreased to 32.9℃, therefore lesser flow rate of air is required to cool the water to 30℃. The temperature range of inlet condenser water is changed from 5℃ to 2.9℃, which is decreased by 42%. As a result of that, the speed of cooling tower fans is proposed to reduce by 42% so that maximum energy saving is achieved. The speed control is achieved by using variable-speed drives (VFD) to control the fan motor's supplied voltage and power. The usage of VFD is very well known with its effectiveness and capability in providing energy saving. Saidur (2011) found out that by matching required speeds using VFD for cooling tower fan motor, able to gain 60% of speed reduction [12].

The condensate system proposed that condensate collected from AHUs is supplied to one 3-cell cooling tower for 5 to 10 minutes of every hour, this is because the amount of condensate recovered is greatly insufficient to continuously supply to the cooling tower. Therefore, further analysis is focusing on how minimum supplying time (5 minutes) of condensate to one 3-cell cooling tower able to save the usage of electricity.

Cooling Tower Fan (One-Cell) proposed speed reduction:

$$Speed = 374\ RPM \times 58\% = 216.92\ RPM$$

Power required, P_2 of fan motor at fan speed of 216.92 RPM by using Fan Law:

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3 \quad ---\ (13)$$

$$\frac{(7.5\ kW)}{P_2} = \left(\frac{374\ RPM}{216.92\ RPM}\right)^3$$

$$P_2 = 1.46\ kW$$

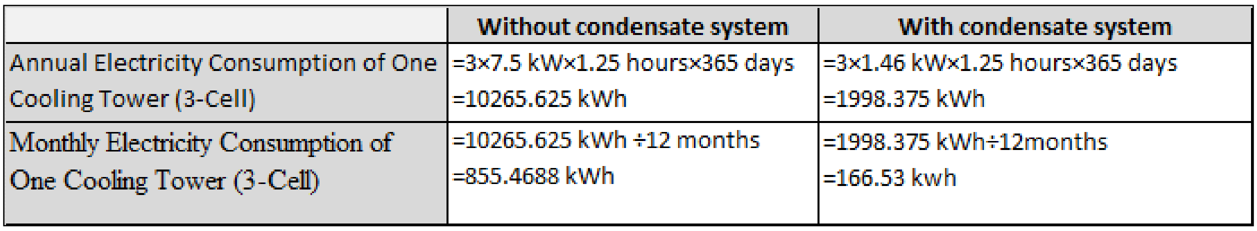
Total time of condensate supply to cooling tower in a day:

$$= 5\ {}^{minutes}/_{hour} \times 15\ hours$$

$$= 75\ minutes = 1.25\ hours$$

Energy saving is calculated based on the difference of fan motor power input between original system and utilization of condensate system. Fan motor input power is directly proportional to the speed of cooling tower fan, decreasing temperature of inlet condenser water results in reducing of electricity usage as the fan motor input is greatly reduced.

Table 7: Comparison on Electricity Consumption of One Cooling Tower (3-Cell)



	Without condensate system	With condensate system
Annual Electricity Consumption of One Cooling Tower (3-Cell)	=3×7.5 kW×1.25 hours×365 days =10265.625 kWh	=3×1.46 kW×1.25 hours×365 days =1998.375 kWh
Monthly Electricity Consumption of One Cooling Tower (3-Cell)	=10265.625 kWh ÷12 months =855.4688 kWh	=1998.375 kWh÷12months =166.53 kwh

Energy Saving:

$$= 855.4688\ kWh\ - 166.53\ kWh$$

$$= \mathbf{688.94\ kWh}$$

CONCLUSION AND FUTURE RECOMMENDATION

Energy saving is focused in reducing the cooling tower fan motor power input and speed according to fan laws. The cooling tower fan motor power input of 7.5kW and fan speed of 374RPM are reduced to 1.46kW and 216.92 RPM respectively. The reduction of fan motor power input able to save 688.94kWh of energy per month which indirectly contributing to lower carbon emission to environment. In future, proper measurement method can be used to precisely measure the amount of condensate such installing flow meter, sensor and thermometer at condensate discharge pipeline. It was advisable to increase the number of AHU involved in the research so that the condensate able to channel to cooling tower at great amount while preserving its coldness. A simulation model for mixing flow of condensate for all selected AHU can be developed for better prediction. Calculation on the return of investment including all cost involve in embedding the condensate system should also been studied in future.

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