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Performance Analysis of Absorption and Electric Chillers at a Gas District Cooling Plant

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ABSTRACT

The research presents a study on chillers performance at a gas district plant during peak and off peak periods for campus cooling. The plant is designed to produce electrical power and chilled water from a Co-generation System and supply the chilled water and electricity to the campus. Since the campus chilled water supply depends solely from the chillers operations, the status of the performance of the chillers need to be continuously evaluated. Using Coefficient of Performance (COP), the performances for both the absorption and electric chillers were analysed. This COP analysis is the follow up from the earlier evaluation which was done in the year 2005. Results of the analysis indicate that there is a decrease in performance for the year 2011 in comparison to the year 2005. In terms of chilled water production the performance decreases approximately by 5%. While in terms of coefficient of performance there is a decrease by 43% from the year 2005 for the absorption chillers and 32% increase for Electric the chillers.

Key words: Co-generation system, coefficient of performance, electric chillers, absorption chillers, gas district cooling

INTRODUCTION

Co-generation could improve overall energy efficiency from 30% to 70% or more (Yin *et al*., 2010). There are a number of district cooling systems that have been installed to cogeneration plants in Malaysia. Among the plants that have been installed with district cooling system are Kuala Lumpur City Center, Kuala Lumpur International Airport, Government Offices in Putrajaya and Universiti Teknologi PETRONAS (UTP). The UTP co-generation plants is equipped with 2 units gas turbines each with 4.2 MW capacity, 2 units heat recovery steam generator (HRSG), 2 Units Steam Absorption Chillers (SAC) and 4 units Electric Chillers (EC) and one unit Thermal Energy Storage (TES). The plant supply electricity and chilled water to UTP.

The current cooling capacity of 4,000 RT inclusive of TES is capable for future extension up to 11,000 RT. Each of the EC is capable to produce 325 RT, while each of absorption chillers has a capacity of 1250 tons of refrigerant (RT). Figure 1 shows the schematic diagram for GDC Plant at UTP.

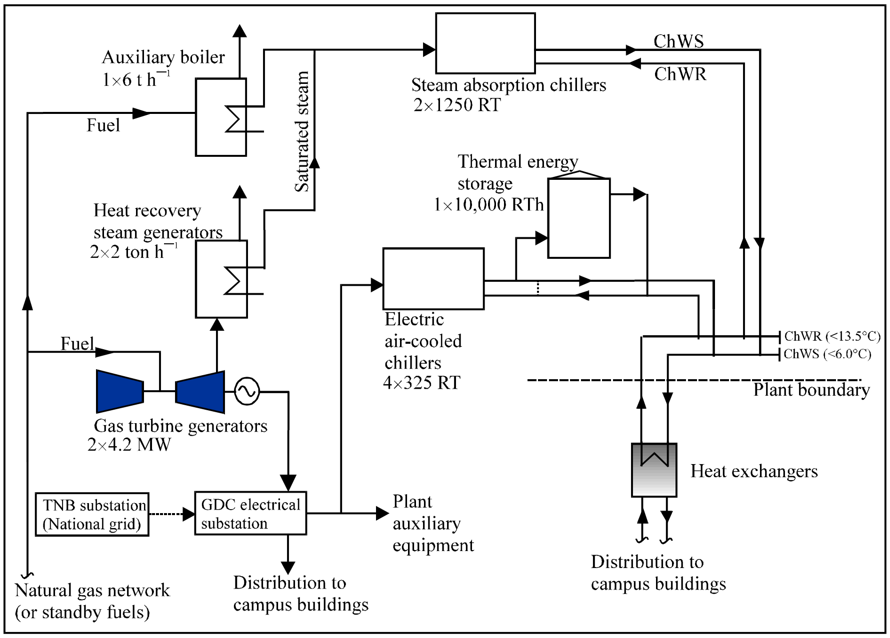

Fig. 1: Process flow of GDC plant at UTP (UTP, GDC project technical document in 2003)

Since, the plant is operated for 24 h and the chilled water supply depends solely to SACs and ECs, the study of chillers performance at GDC plant is important. This study focuses on production and coefficient of performance (COP) of SACs and ECs. The first phase of the study covering the actual load and performance of the chillers, operating with two SACs and four ECs during the day and only two ECs operating at night for TES charging. The second phase of the study considered one of the SACs is under overhauled and only one SAC is operating with four ECs during the day. Analysis scope covers daily set of data within November 2011.

Two studies that have been done related to chillers at UTP. Gilani *et al.* (2006) reported that the chillers in UTP GDC plan were operated at below rated capacity. While research by Rangkuti *et al.* (2006), based on analysis of operating data of the steam absorption chillers on hourly, daily and monthly basis shown that the average COP of both chillers was around 1.2 and the load factor was 75 to 85%.

MATERIALS AND METHODS

The system performance is evaluated in terms of the coefficient of performance (COP) Steam Absorption Chiller (SAC) and Electric Chiller (EC) as per Eq. 1-4.

$$\text{COP (SAC)} = \frac{\text{Tones of refrigeration h (RTH)}}{(\text{Steam flow h}^{-1}) \times (\text{Steam enthalpy} - \text{SAC drain entholpy})} \qquad (1)$$

$$\text{COP (SAC)} = \frac{\text{Refrigeration (RTH)}}{\text{Steam (kg)} \times (0.2189 - 0.0287)} \qquad (2)$$

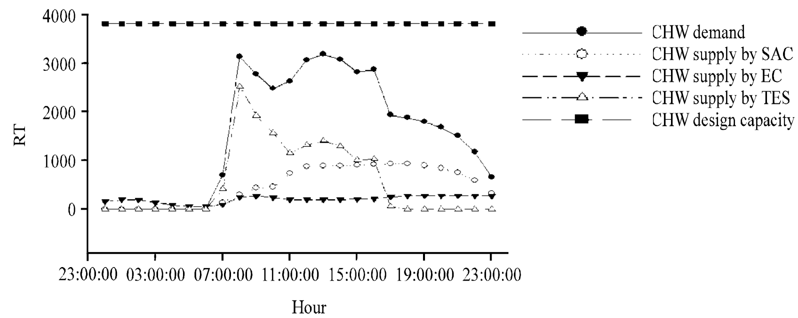

Fig. 2: Typical CHW daily supply in 2010

Where:

Steam Enthalpy = 0.2189 RT kg^{-1} at 8.5 bar

Steam Absorption Chiller Drain (90°C) = 0.0297 RT kg^{-1}

$$COP(SAC)=\frac{\text{Tones of refrigeration (RTH)}}{\text{Equivalent power input to compresser}} \quad (3)$$

$$COP(SAC)=\frac{\text{Refrigeration (RTH)}}{\text{Electricity }(kWh^{-1})\times 0.2844} \quad (4)$$

Coefficient of performance is analyzed during peak and off peak periods where the peak period covers from 7 a.m. to 6 p.m. While the off-peak period covers from 6 p.m. to 7 a.m. in the morning. During the off peak period, electricity requirement by the campus is low and hence the excess electricity is used by electric chillers to charge the TES tank.

Figure 2 shows the typically chilled water daily supply in UTP in 2010. CHW supply by TES is the highest capacity compared to SAC and EC during 7.00 a.m. to 7 p.m. Following by SAC which provide supply from 7.00 a.m. to 11.00 p.m. The total capacity from the three sources SAC, EC and TES support the CHW demand by UTP. TES were charged by EC at night from 6.00 p.m. to 6.00 a.m.

The analysis was based on the hourly data of the chilled water produced. The first phase of the study covering the actual load and performance of the chiller based on two SACs and four ECs operating during the day and only two ECs operating at night for charging of TES.

The second phase of the study is covering only one SAC and four ECs operating during the day. The other SAC was not operated as it was under overhauled. Analysis scope covers data set of 2005 data and data set during November 2011.

RESULTS AND DISCUSSION

Results of the first phase: Figure 3 shows the chilled water production by SACs and ECs on 01/11/2011. The coefficient of performance of SACs and ECs are shown in Fig. 4. Both of SACs were operated during the day and early part of the night to supply chilled water to customer while the EC chillers were operated randomly based on the predetermined schedule. Detailed on the chilled water production and the performances for the both chillers are included in Table 1 and 2.

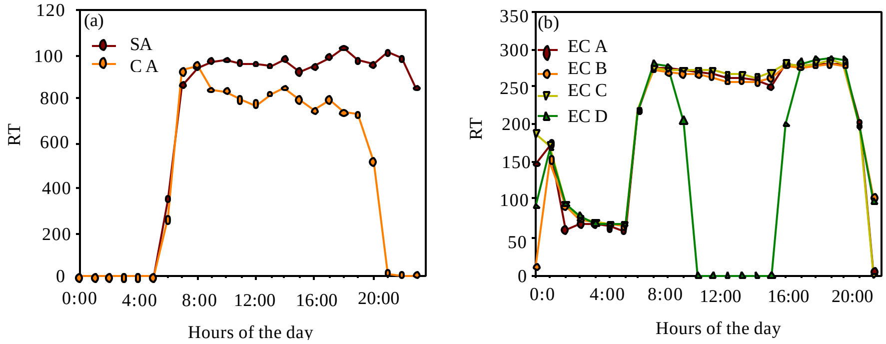

Fig. 3(a-b): Chilled water production by (a) SAC's and (b) EC's on 01/11/2011

Table 1: Chilled water (CHW) production by steam absorption chillers on 01/11/2011

		Chiller's output/h (RTh)	Coefficient of performance (COP)
SAC-A	Min.	8.65	0.53
	Max.	1034	0.87
	Avg.	956	0.75
SAC-B	Min.	516	0.26
	Max.	950	0.71
	Avg.	795	0.63

Table 2: Chilled water (CHW) production by electric chillers on 01/11/2011

		Chiller's output/h (RTh)	Coefficient of performance (COP)
EC-A	Min.	59	2.86
	Max.	282	5.31
	Avg.	211	4.40
EC-B	Min.	64	1.43
	Max.	280	3.79
	Avg.	208	2.96
EC-C	Min.	67	2.06
	Max.	284	3.75
	Avg.	208	3.10
EC-D	Min.	67	2.02
	Max.	286	3.77
	Avg.	180	3.00

Some of the points that are noted for the chilled water production:

- The production of chilled water using two SACs and four ECs to supply chilled water daily demand. The maximum chilled water production was 1,034 RTh produced by both SAC-A (refer to Table 1). The production is lower compared from 2005 (Rangkuti *et al.*, 2006). The total daily production of both SACs was 28,038 RTh
- For the electric chillers total production for EC-A was 4,872 RTh day^{-1}, EC-B was 4,800 RTh day^{-1}, EC-C was 4,992 RTh day^{-1} and EC-D was 3,240 RTh day^{-1}. The total production is higher compared to the production reported in 2005 (Rangkuti *et al.*, 2006)

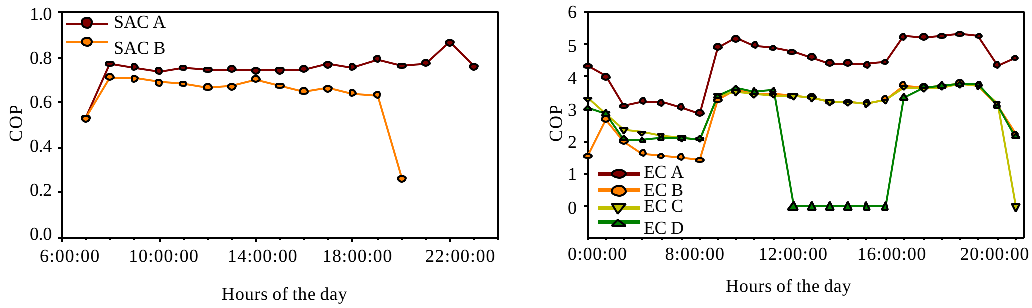

Fig. 4(a-b): Coefficient of performance (COP) of SAC's and EC's on 01/11/2011

- Figure 3 show that four ECs contributed only 39% of the chilled water requirement whereas the 61% of the chilled water requirement was fulfilled by the two SACs. The initial design, the generation plant would be able to fulfill chilled water production by SACs is 66% while ECs is 34%. It shows that SAC's production is decreasing while EC's production is increasing
- Figure 4 shows the coefficient of performance (COP) of SACs and ECs. The COP depends on the chilled water production where the performance increases with increase production

Some points that can be noted from the findings are as follows:

Steam absorption chiller (SAC):

- Figure 4 shows that the performance SAC-A is better than SAC-B. The line graph indicates approximately constant values from 8.00 a.m. to 7.00 p.m. This is due to high demand of CHW during this period. The highest performance is 0.87 which is by SAC-A
- The maximum operating h of SAC was 18 h. The average chilled water production of SAC-A is 956 RTh while SAC-B is 795 RTh
- As shown in Table 1, the highest performance of SAC-A is 0.87 while SAC-B achieved maximum value of 0.71
- The average performance of both SAC is 0.69 which is lower than the performance during 2005 (Gilani *et al*., 2006).

Electric chiller (EC):

- For the ECs, the findings indicate that performance of EC-A is better than the other three ECs. EC-D was not operated from 11 a.m. to 4.00 p.m. All the EC chillers were operated based on predetermined schedule and the daily demand
- The line graphs of ECs show variation in the performance of ECs. It is noted that all ECs were operated during the night to charge TES
- Table 2 indicates that EC-A has the highest performance which is 5.31. This might be due to power consumption of EC-A is low compared to other EC chillers

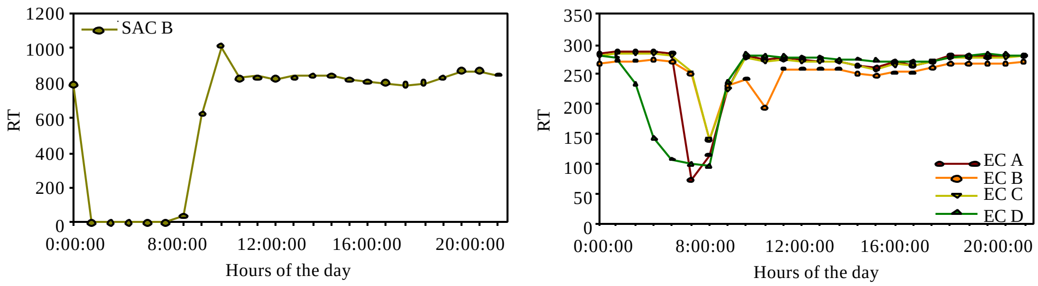

Fig. 5(a-b): Chilled water production by SAC's and EC's on 24/11/2011

- The average performance of the ECs is 3.37 and this is higher than performance during 2005 (Gilani *et al*., 2006). Performance of ECs is better than during 2005 due to higher utilization compared to 2005

Results of the second phase: During the study period, one of the SAC was undergoing major overhaul. Hence the plant was operating with one SAC. The effects using one steam absorption chiller is shown in Fig. 5.

The points noted for the chilled water production with one SAC operating:

- SAC-B running at a normal operation which was from 5.00 a.m. to 11.00 p.m. The output varies from 623 RTh to 1,011 RTh. The production of chilled water was insufficient
- The lower graph shows the production of chilled water by EC. The pattern of the graph differs from that of 01/11/2011. It is noted that all the chillers were running the whole night to charge the TES
- All EC were operating at lower capacities from 5.00 a.m. to 6.00 a.m. before operating at normal capacities
- Figure 6 shows the coefficient of SACs and ECs on 24/11/2011. It indicates the performances of the chillers when one of the SAC is not in operation

The following points are noted from the plot Fig. 6:

Steam Absorption Chiller (SAC):

- The COP of SAC-B increases compared with COP on 1/11/2011. This indicates that the SAC will be able to achieve the expected performance when sufficient steam supply is available
- The average hour production of chilled water by SAC-B is 828 RTh and the total production on the whole day is 14,076 RTh
- Table 3 shows that the average COP of SAC-B is 0.68 which is higher than COP of SAC-B on 1/11/2011

Electric chiller (EC):

- Table 4 is presenting the chilled water (CHW) production by electric chillers on 24/11/2011
- The COP of EC-B, EC-C and EC-D are in the same range which is from 3.0 to 4.0, while COP-A

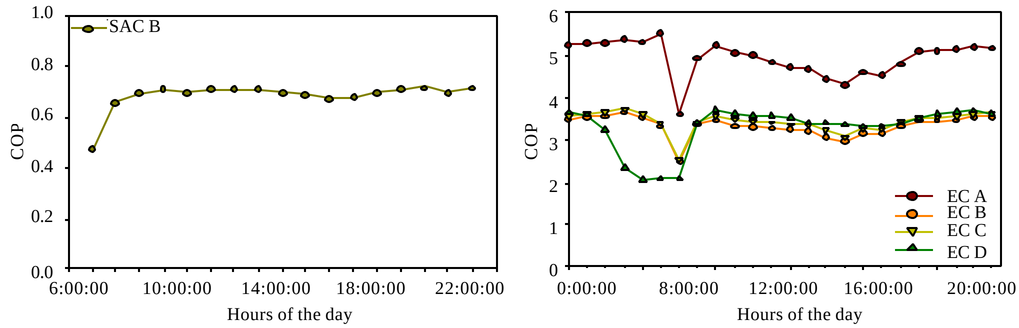

Fig. 6(a-b): Coefficient of performance (COP) of SAC's and EC's on 24/11/2011

Table 3: Chilled water (CHW) production by steam absorption chiller on 24/11/2011

		Chiller's output/h (RTh)	Coefficient of performance (COP)
SAC-B	Min.	623	0.47
	Max.	1011	0.72
	Avg.	828	0.68

Table 4: Chilled water (CHW) production by electric chillers on 24/11/2011

		Chiller's output/h (RTh)	Coefficient of performance (COP)
EC-A	Min.	72	3.62
	Max.	286	5.53
	Avg.	260	4.90
EC-B	Min.	140	2.49
	Max.	274	3.67
	Avg.	252	3.30
EC-C	Min.	141	2.55
	Max.	285	3.75
	Avg.	267	3.40
EC-D	Min.	137	2.47
	Max.	287	3.79
	Avg.	270	3.50

reaches maximum COP of 5.53, similar to COP indicated in the plot in Fig. 4. This was due to EC-A using low power than other chillers whereas the chilled water being produced was approximately the same capacity

- The average hour production of chilled water by EC-A, EC-B, EC-C and EC-D were 260, 252, 267 and 270 RTh, respectively. The total production for all chillers is 25, 176 RT
- The average COP of the EC-A, EC-B, EC-C and EC-D was 4.90, 3.30, 3.40 and 3.50, respectively
- The findings indicate that COP of EC-A is also higher than COP of other EC. Hence, EC-B, EC-C and EC-D need to be rechecked and appropriate action taken

CONCLUSION

Based on the analysis result, the following conclusions are arrived:

- Performance of the SAC ranges from 0.63 to 0.75. The performance is lower than the performance during 2005 (Rangkuti *et al*., 2006), however compared to normal performance of SACs which is in the range of 0.5 to 1.5 (Somers *et al.*, 2011), it is on lower side. Among the possible reasons COP is on lower side are due to insufficient steam and deteriorating condition of the SAC. Hence, the SACs should be rechecked

- The performance of EC improved compared to performance during 2005 (Gilani *et al.*, 2006), however the average COP of EC is lower than the normal range of EC COP which is between 4.2 to 6.10 (ASHRAE, 2010). Hence, all EC especially EC-B, EC-C and EC-D need to be rechecked
- Further study is required to ascertain the amount of chilled water that is required to be produced by the SAC and EC respectively. This would enable appropriate operating schedule for both the SAC and EC to optimize the operations

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