COST EFFECTIVENESS STUDY OF AN EXISTING COMBINED CYCLE POWER PLANT IMPROVEMENT

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A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING
IN ENERGY TECHNOLOGY AND MANAGEMENT

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT
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ABSTRACT

The degradation of an existing combined cycle plant was investigated, and possible modifications for performance improvement were explored. The case study of Bangpakong Combined Cycle Power Plant was analyzed regarding plant performance, cost effectiveness and economic benefit using the Gate cycle model. The degradation of the power plant was analysed and compared with GE's guaranteed performance guide, and found that net output improvement and net heat rate improvement of gas turbines were negative, where net heat rate improvement was approximately -12.7%. It is therefore implied that an improvement in the performance of the gas turbine would be most effective. For applications where significant power demand occurs during the high ambient temperature, a useful option for increasing output is a gas turbine air inlet cooling system. Different types of air inlet cooling systems, such as evaporative system, mechanical chiller system and absorption chiller system were considered. The inlet temperature, parasitic load and flue gas temperature were the key factors that contributed to the improvement of the combined cycle plant's performance. The evaporative system was found to provide the greatest heat rate improvement, while the absorption chiller system was found to generate the greatest power augmentation at 2.5%. The cost effectiveness analysis showed that the evaporative cooling system was the best alternative option for performance improvement for the BPK combined cycle power plant with the net present value of US$ 730,001 in 8 years of useful life, while the primary energy saving dropped by 0.58%.

Keywords: Combined Cycle Power Plant, Primary Energy Saving(PES), Feasibility, Gas turbine air inlet cooling system

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CHAPTER 1

INTRODUCTION

1.1 Rationale/Problem Statement

New clean technologies of power plants and renewable energy systems are studied by many researchers around the world. Meanwhile, some researchers are still interested in the development of existing power plants. Various developments are available for an existing power plant, including efficiency improvement, operating and maintenance cost reduction, in order to maintain energy security and mitigate climate change impacts.

In terms of environmental effects, overall production cost is the key point to success. If power plants they can utilize the fuel in the most benefit, they could acquire more profit and also reduce energy consumption. At the present, owners and operators are seeking cost effective ways to expand power plant operability, improve efficiency, gain more output and extend the life of their existing equipment. The regulatory process for permitting new generation sources is slow and more demanding than ever before, so making minor improvements to existing equipment is considered an attractive option.

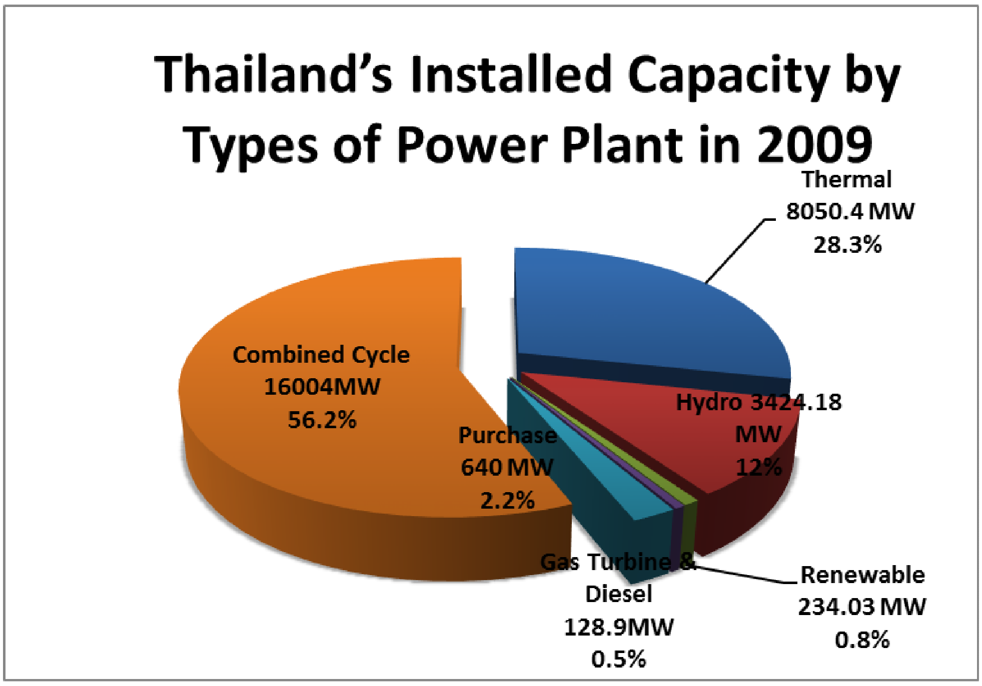


Figure 1.1: Thailand's installed capacity by types of power plant in 2009

The existing Bangpakong Combined Cycle Power Plant Block 4 (BPK-CC Block 4) has been in commercial operation since 1994. Therefore the performance of each components reduce. To solve mechanical degradation and improve performance, most of components of the gas turbine section were modified to be efficiency on improvement by using GE’s advance technology up rate options in 2005. A variety of technologies available for enhancing can be made in plant output or efficiency beyond those achievable through higher steam temperatures, multiple steam-pressure levels or reheat cycles. Gas turbine enhancing; advanced sealing technologies improve parasitic leakage control implement for enhancing performance. From brush seals and cloth seals to the optimized clearances of the sacrificial honeycomb seal, sealing technologies balance and minimize airflow leakage from the power production path. The power plant acquires higher effective output power.

Some parts equipment of the steam turbine section have been replaced by new technology, such as pump type, pump capacity and valve type. The operation setting points and controls are changed to solve problems which usually occur during operation. There are many operating system controls, parameters and components which are totally complex. Many parts that have improved can solve each problem but all improvements mostly affect to the other systems in the power plant and effect on efficiency of power plant.

This research study for new options to enhance the performance of the power plant. For existing plants, some performance enhancement options can also be economically retrofitted to boost power output and efficiency. The simulation model of the combined cycle power plant can help engineers modify more easily and certainly decide to select appropriate solutions like choosing the new technology additional options. The heat will generally be used more efficiently, improving the performance but also increasing cost. In practice, a compromise between performance and cost must always be made. This project is provided for performance improvement of the existing power plant include with considering of cost effectiveness.

1.2 Literature Review

The literature review consists of two parts: the first part is the specifications of existing BPK-CC Block 4, and the second part presents potential technologies that can enhance the performance.

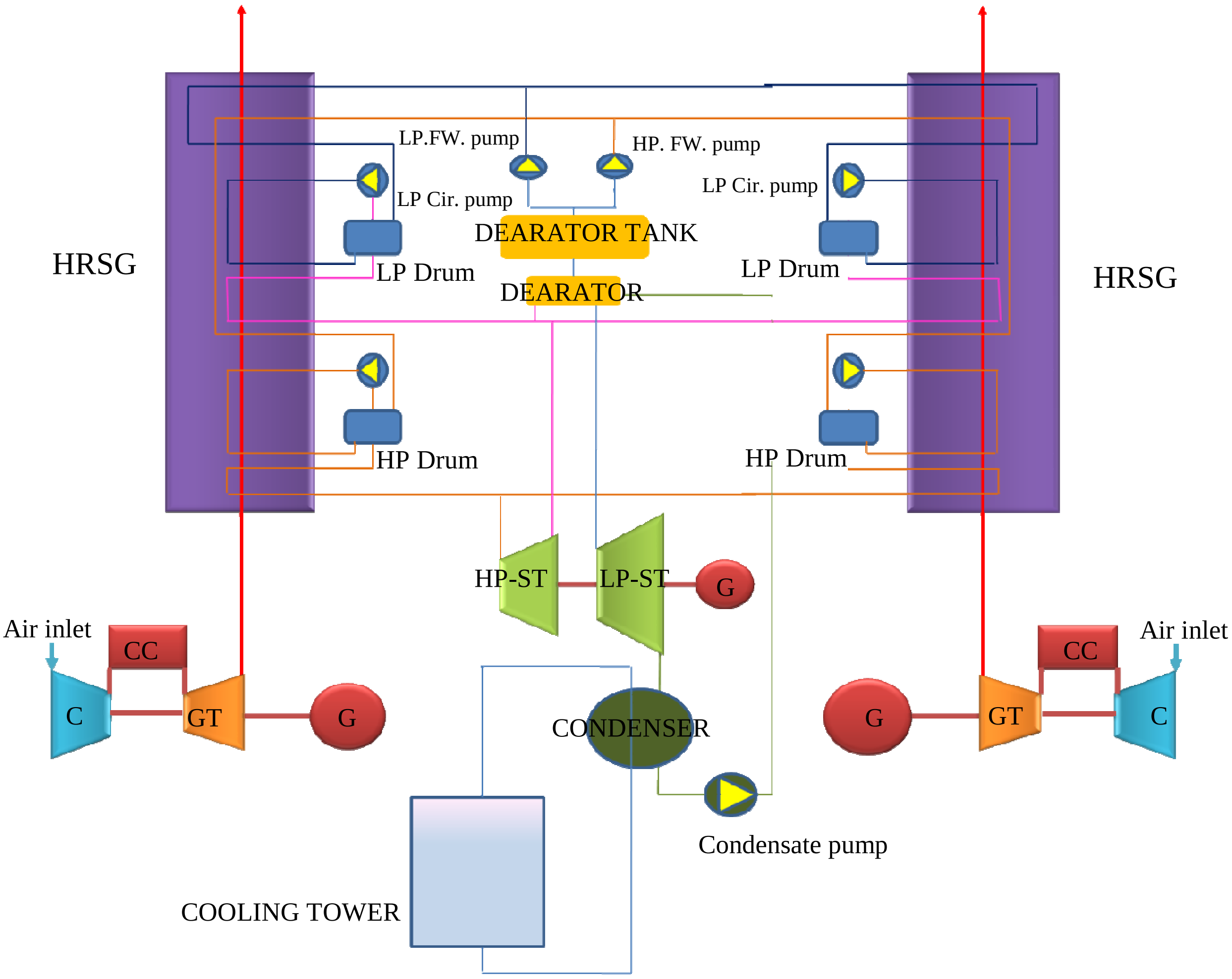
1.2.1 Existing BPK-CC Block 4 specifications

The major sets of equipment of BPK – CC Block 4 and the process diagram are shown in Figure 1.1. BPK – CC Block 4 is a multi-shaft combined cycle system that has two gas turbine generators and two HRSGs, in which supply steam through a common header to a single steam turbine-generator. Gas turbines are heavy duty industrial gas turbine served by GE and natural gas is supplied for generating electricity. The vertical heat recovery steam generators (HRSG) without supplementary firing are a link between the gas turbines and steam turbine process. Each HRSG is arranged with a high-pressure (HP) super-heater, HP drum, HP evaporator, HP economizer, low-pressure (LP) super-heater, LP drum, LP evaporator, LP economizer, and an exhaust stack. Table 1.1 describes the details of machines and equipment used in BPK-CC Block 4 with specification and design criteria.

Table 1.1: Details of machines and equipment used in BPK-CC Block 4

	Design Data
Gas Turbine	
General Data on ISO Condition	
Manufacturer	General Electric
Type	MS-9001E
Design Condition	ISO. Condition – 15^{o}C amb., 1.013 Bar,60%RH
Design Point	
Air Flow	1,450 Ton/hr
Turbine inlet Temp.	1104 ^{o}C (Base), 1160 ^{o}C (Peak)
Turbine Exhaust Temp.	529 ^{o}C (Base), 565 ^{o}C (Peak)
Output	116.4 MW (Base), 125.7 MW (Peak)
Consumption	39,722 Nm^{3}/Hr (Base), 42,788 Nm^{3}/Hr (Peak)
Heat Rate	10,880 kJ/kWh (Base), 10,840 kJ/kWh (Peak)

Name Plate Data	
Output	103.75 MW (Base), 113.188 MW (Peak)
Turbine Exhaust Temp	540 ^oC
Pressure	14.0 H_2O
HRSG	
Manufacturer	Cockerill Mechanical Industries
Type	Dual Pressure Waste Heat (Combustion Turbine Exhaust), Boiler with Assisted Circulation
Design Steam Capacity	166,802 kg/hr HP, 39,765 kg/hr LP
Operating Pressure	82.44 Bar HP, 8.5 Bar LP
Drum Design Pressure	96.99 Bar HP, 11.99 Bar LP
Steam Temperature	512^{o}C HP superheat outlet 235^{o}C LP superheat outlet
Steam Turbine	
Manufacturer	Toshiba
Type of Turbine	Tandem Compound 2 cylinders 2 Flow Exhaust Turbine
Rated Output	109 MW
Steam Condition	HP. Steam Pressure 78.5 Bar, Temp. 509 ^{o}C LP. Steam Pressure 7.0 Bar, Temp. 232 ^{o}C
Exhaust Vacuum	63 mmHg abs
Generator	
Gas Turbine Generator	128,600 KVA
Steam Turbine Generator	145,000 KVA



C = Compressor
LP = Low Pressure
CC = Combustion Chamber
HP = High Pressure
GT = Gas Turbine
Cir. = Circulating
G = Generator
FW = Feed Water

Figure 1.2: Process diagram of BPK-CC Block 4

1.2.2 Potential technologies

For applications where significant power demand and the highest electricity prices occur during the warm months, a gas turbine air inlet cooling system is a useful option for increasing output. Inlet air cooling increases output by taking advantage of the gas turbine’s characteristic of higher mass flow rate and, thus, output as the compressor inlet temperature decreases [13]. Since the gas turbine is an ambient-air breathing engine, anything affecting the mass flow of the air intake to the compressor will changed its performance. The most effective parameter affecting the performance of a gas turbine is the inlet air temperature. Figure 1.3 shows how ambient temperature affects output, heat consumption and exhaust flow. Similarly, humid air, being less dense than dry air, will also have an effect on output and heat rate [1]. Augmentation to the equipment, i.e. air filtration, silencing, evaporative cooler, chillers in the inlet or exhaust heat recovery devices cause pressure drop in the system. This pressure loss effect on exhaust temperature increasing, heat rate increasing and power output reduction.

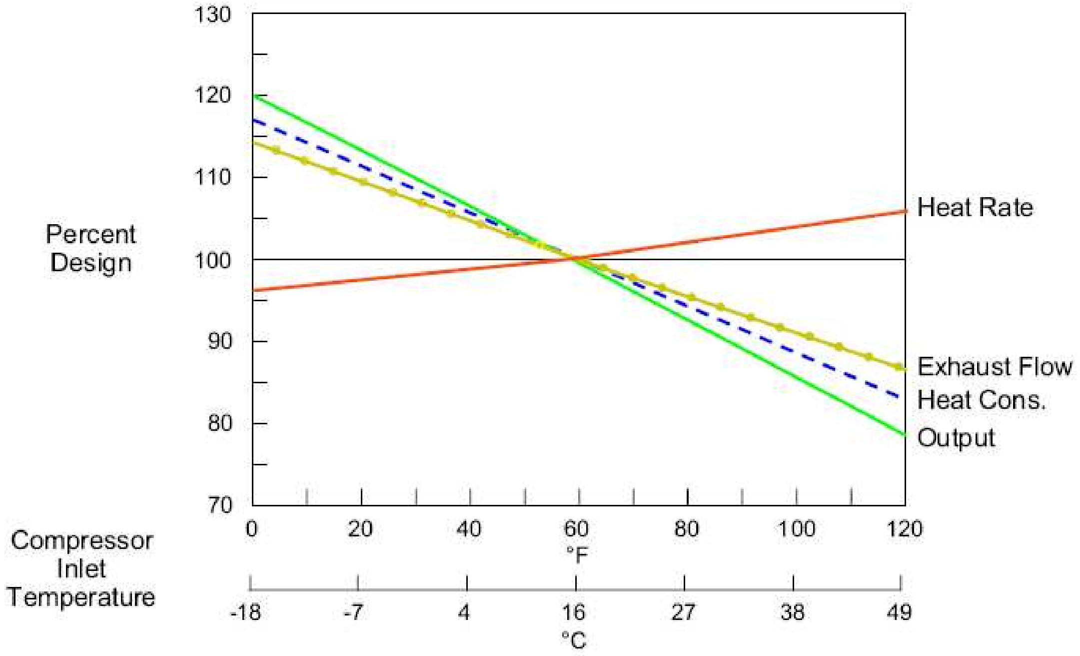


Figure 1.3: Effect of ambient temperature [1]

Inlet Air Cooling System

The gas turbine is a standardized machine in which the performance design basis conforms to ISO condition, 15^{o}C dry bulb, 7.2 ^{o}C wet bulb, 60% RH and 1 bar, so that the machine can be used for widely difference ambient conditions. Most gas turbine installations are not in ISO standard locations. General gas turbines perform differently at different ambient condition thereby this will have an effect on performance and steam process. One of the most significant shortcomings affecting gas turbine behavior is their power output decreases at higher air ambient temperature.

There are three reasons why the air temperature has a significant influence on the power output and efficiency. Firstly, gas turbines always draw in a constant volume flow to compressor. Increasing the ambient air temperature reduces the density of air and thereby reduces air mass flow contained in the constant volume flow. Secondly, the specific volume of the air increases in proportion to the intake temperature, increasing the power consumed without a corresponding increase in the output from the turbine. Thirdly, as the air temperature rises and the mass flow decreases, the pressure ratio within the gas turbine is reduced, because as the swallowing capacity of the gas turbine is given, the law of sines reduces the pressure before the turbine. The same principle applies inversely to the compressor, but because the turbine is dominant, total balance is negative [2]. Many technologies are commercially available for inlet air cooling systems. These technologies can be divided into the following major categories:

- Evaporative: wetted media, fogging, and wet compression/overspray
- Chillers: mechanical and absorption chillers without or with thermal energy storage (TES)
- Hybrid Systems: combinations of several technologies

Evaporative Cooling System

Evaporative Cooler/Wetted Media: Figure 1.5 shows a schematic of evaporative air cooling system. [3] The method of an evaporative cooling system is cooling of the air stream by adding a media evaporative cooler which converse water from liquid to vapor, called a phase change. The phase change process, air is pulled through media, it evaporates water off the convoluted surface. Heat of vaporization is absorbed from the air, and cooling occurs. Although air temperature decreases, the evaporative cooling produces higher specific humidity airflow downstream of the equipment. As evaporative coolers are limited by the amount of moisture present in the air. [4] Once saturation (i.e. 100% relative humidity) is reached, evaporative cooling systems are unable to evaporate more water into the air stream.

For this reason, in hot, humid regions, it is not often possible to accomplish more than about 10 to 15ºF of cooling. In low-humidity environments they are capable of increasing power output by as much as 15%, while in high humidity areas, the power boost tends to be 10% or less. One factor to be considered is the cost of retrofitting and installing. Although the units themselves are generally fairly inexpensive, installation usually calls for duct enlargement, as evaporative coolers require relatively low air velocities. If the air velocity across the wetted media is too high, it can strip water from the media, cause excessive wetting of the ducts and even fouling of the compressor blades.

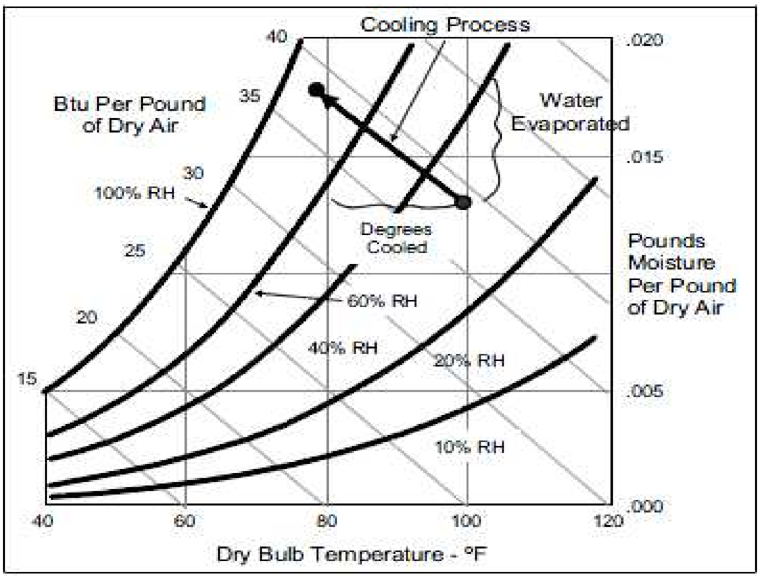


Figure 1.4: Evaporative air cooling system psychometric chart, simplified

Figure 1.4 is a simplified psychometric chart. The cooling process follows a line of constant enthalpy as sensible heat is traded for latent heat by evaporation. The exact increase in power available from a particular gas turbine as a result of air cooling depends upon the machine model and the site altitude, as well as on the ambient temperature and humidity. [13]

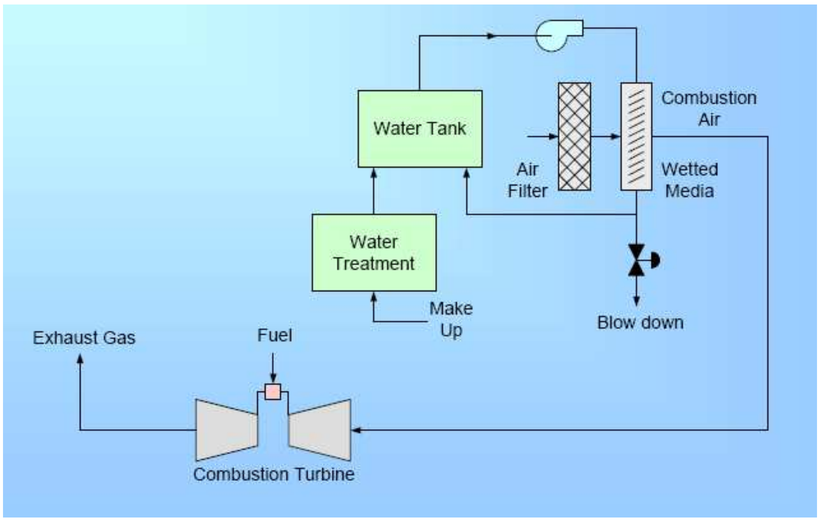


Figure 1.5: Schematic of evaporative air cooling system

High Pressure Fogging System: Fogging systems are similar to media type evaporative cooling systems in that they cool by evaporating water, but instead of using an evaporative medium, the water is atomized into billions of super-small fog droplets [4]. A schematic diagram of the technique is show as Figure 1.5 [3]. The system carefully controls the amount of injected water to ensure no large droplets of water are ingested into the compressor. [5] States that humid air cannot exceed 90% of relative humidity. In order to prevent erosion in the compressor blades, it is also advisable that dry bulb temperature exceeds 1^{o}C over wet bulb temperature at the GT inlet duct to avoid condensation. It should be noticed that both limitations must be simultaneously observed.

Chiller

Mechanical Chiller without TES: Mechanical Chiller systems can reduce the inlet air to much lower temperatures than those possible by drawing air through evaporative cooling and they can maintain any desired inlet air temperature down to the required temperature, independent of ambient wet-bulb temperature, but it is capital cost intensive and also has higher parasitic loads. The mechanical chillers used in these systems could be driven by electrical motors or steam turbines. Figure 1.6 shows a schematic of the system connected to a simple gas turbine.

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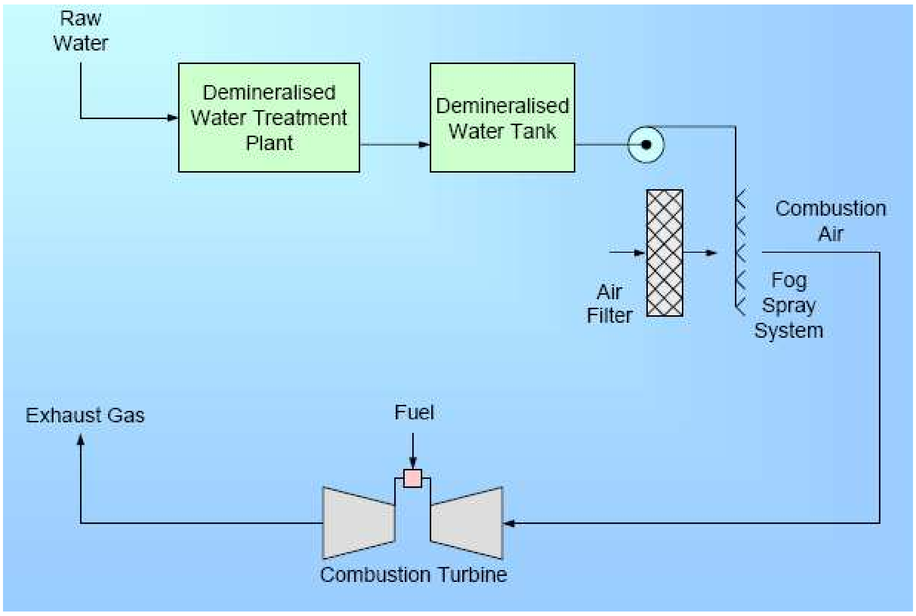


Figure 1.6: Schematic of high pressure fogging system

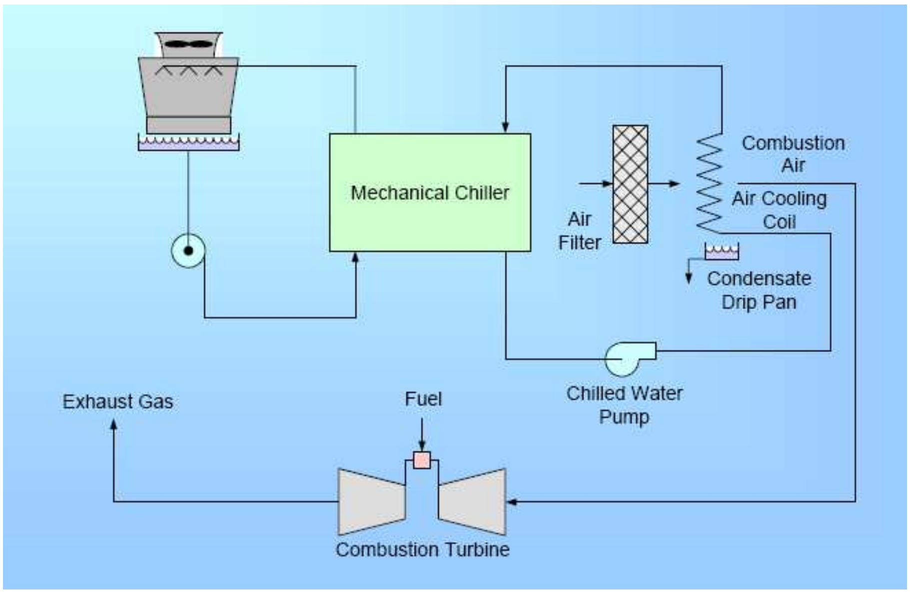


Figure 1.7: Schematic of inlet air cooling system by using mechanical chiller without TES

The cooling load was calculated where the compressor inlet humid air is cooled by ejecting its total heat to the chilled water. As the air temperature drops, its relative humidity would continually rise to 100% RH. This load can be calculated in terms of ton refrigeration (RT) or energy per hour, which will be extracted from an inlet compressor air to meet the 15 1C (ISO), 100% RH. This cooling process consists of two steps, which are latent heat (a–d) and sensible heat (d–c) which is shown in Figure 1.7. There are some water vapors condensing on the cooling coils. To avoid damage to the system, this condensate has to be eliminated by adding a separation system at the entrance of the air compressor.

Heat Absorption Chillers without TES: Absorption Cooling systems are similar to the mechanical refrigeration systems except that instead of using mechanical chillers, these systems use absorption chillers that require thermal energy (steam or hot water) as the primary source of energy and require much less electrical energy than to the mechanical chillers [6]. The proper thermal source for the absorption chiller is an extraction of the combined cycle low pressure steam. Thermal utilisation is set to 750 kW of heat per 1000 kW of chilling power [5].

Mechanical Absorption chiller and Heat Absorption Chillers with TES. The mechanical and absorption cooling systems whose refrigerants can achieve temperatures below 0 ^{o}C allow ice to be stored for cold thermal energy uses in demand peak periods or when operation is more profitable. It is important to notice that some factors influence CC in the storage process time, whereas others only do so when the air is being cooled. Chillers with ice storage must be designed with lower cooling power than other alternatives, since the necessary ice to cool the air for only a few hours is produced throughout the whole day [5]. A TES is typically used when there are only a limited number of hours required for inlet air cooling. TES can reduce overall capital costs because it reduces the chiller capacity requirements as compared to the capacity required to match the instantaneous requirement on peak demand for cooling.

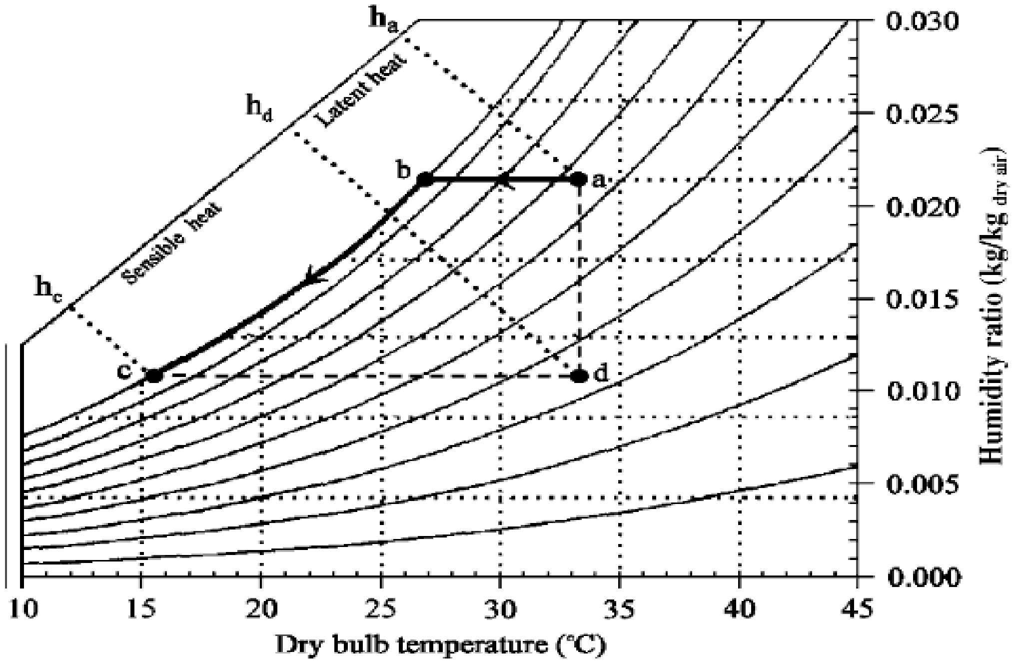


Figure 1.8: Air cooling process in psychometric chart

Hybrid System: this system is a combination of technologies, for example, mechanical and absorption chillers. Such a system is optimized for a specific plant based on the power demand and electrical prices and availability of thermal energy. Other hybrids may include combinations of evaporative cooling and chiller-based systems or chillers with high pressure fogging.

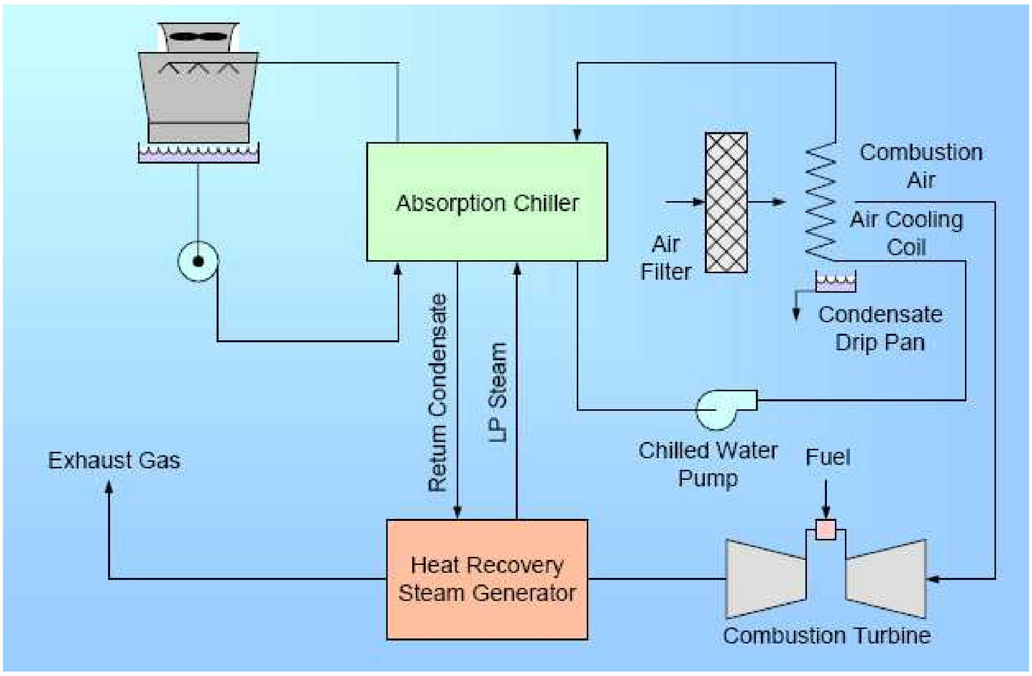


Figure 1.9: Schematic of inlet air cooling system by using absorption chiller

When analysing the most suitable gas turbine (GT) inlet cooling technology to be used in combined cycle (CC) applications into a deregulated electricity market, other variables also must be considered. Firstly, the effects of the cooling system on the bottoming cycle must also be taken into account. Secondly, inlet air cooling not only increases the power output of the topping cycle, but also changes the properties of the GT exhaust gases, causing variations on the heat recovery steam generator (HRSG) temperature profile and steam turbines (ST) power output. Thirdly, the use of steam extractions to fuel the absorption chillers by the air cooling equipment could introduce significant alterations in the CC ordinary performance [5]. Fourthly, the generator capacity must be checked in order not to overload the generator. Table 1.2 shows a comparison of inlet air cooling techniques.

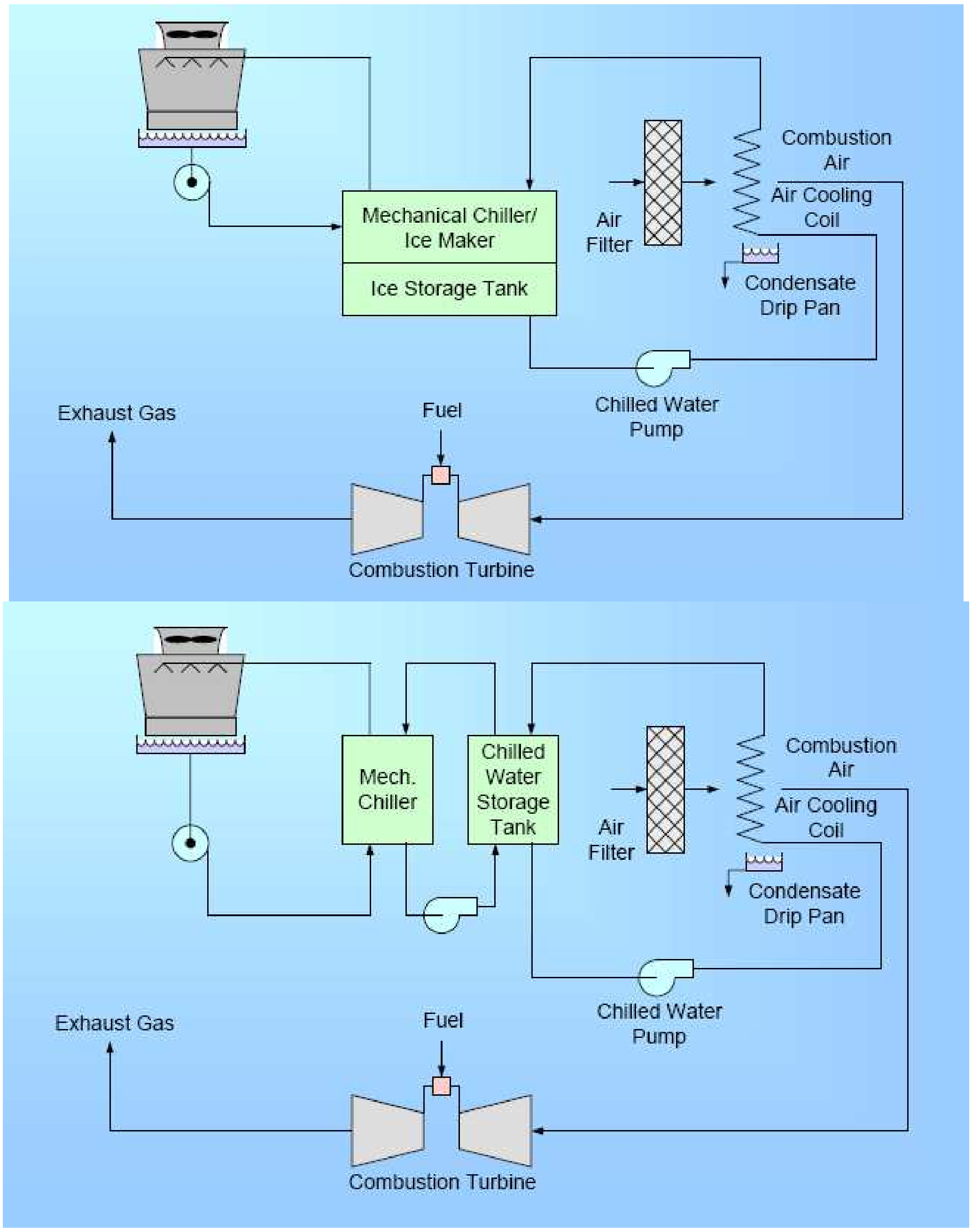


Figure 1.10: Schematic of inlet air cooling system by using mechanical chiller with TES

Table 1.2: Comparison table of inlet air cooling techniques

	Evaporative Cooling	**High Pressure Fogging**	**Mechanical Chiller**	**Absorption Chiller**
Capital cost	Lowest	Low	High	High
O&M cost	Lowest	Low	High	High
Capacity improvement	Limited	Limited	-	-
Effective area	Low RH area	Low RH area	Not very sensitive to RH	Not very sensitive to RH
Delivery and installation timed	Quick	Quick	Long	Long
Can increase performance	Lowest	Low	High	High
Other additional	Raw water	Demineralised water, injection pump	Electrical parasitic load	Steam, Low electrical parasitic load

1.3 Research Objectives

The main objective of this project is to improve the performance of the existing Bangpakong Combined Cycle Power Plant Block 4, of which the procedure is as follows:

- To determine the efficiencies of the equipment/the parts drop by comparing current performances with design values/initial test values.
- To consider the appropriate technologies or solutions to improve the efficiency of the power plant.
- To develop the simulation model of an existing Bangpakong Combined Cycle Power Plant Block 4 and to simulate/calculate the system performances of various solutions.
- To determine cost effectiveness of the technologies or solutions and to compare different performances between an existing plant and the best solution in terms of primary energy saving (PES).

1.4 Scopes of Research Work

For this study, the area to be investigated is Bangpakong Combined Cycle Power Plant Block 4. The solutions are considered as optional in the future. The research covers three main parts as presented in Figure 1.11.

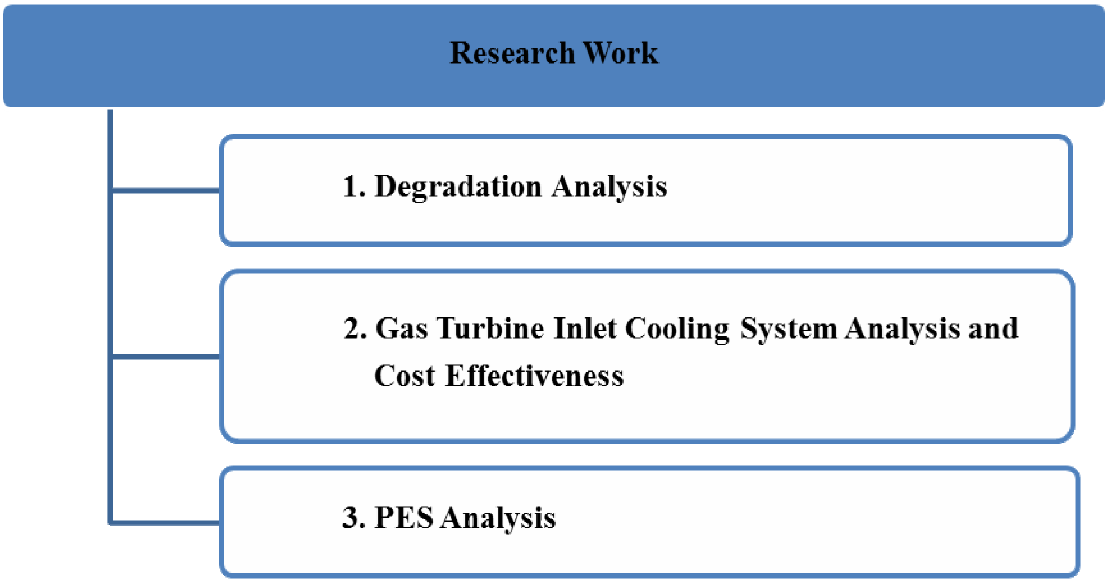


Figure 1.11 Scope of research work

Degradation Analysis:

Both the current performance test data and the initial performance test data were corrected to the same ambient conditions, which is 32.2 °C (average temperature of Bangpakong Power Plant) by using Correction Factor Curve of GE Manufacture. Performance test data base on the base load of Bangpakong Combined Cycle Power Plant (100% load or full load). The performance of power plant was compared to analysis degradation of combined cycle power plant.

Gas Turbine Inlet Cooling System Analysis

The main designs of solutions are focused on the Gas Turbine Inlet Cooling System. The simulation model for research analysis process will be created, applied and solved on Gate Cycle software. For improved gas turbine performance, inlet air cooling systems are selected to increase performance of this plant. The selected additional systems are shown below:

- Evaporative System (High Pressure Fogging System)
- Mechanical Chiller System
- Absorption Chiller System

The sizing of each additional system was created using asimulation model based on the limitations of each technique. Each additional technique was applied to simulation model of an existing plant which was completely calibrated conform to actual operational parameters, and was simulated to the new improved performance.

Cost-effectiveness analysis (CEA) is a tool for the comparison of alternative projects with the same objectives in which it is difficult to value an efficient selection. Cost-effectiveness ratio indicates the best project or the first priority project. It can identify maximize the output power on given cost or minimize the cost on given output value. Expected result of appropriate solutions of the research were generated from simulation data. Then, they were considered in cost effectiveness for selection of the best solution.

PES Analysis:

PES, in comparison with the separate production of heat and power was calculated using the reference values. The amount of primary energy saving (PES) was calculated based on the methodology proposed in the EU directive. The PES analysis will be used to compare energy utilization

CHAPTER 2

THEORIES

2.1 Theoretical Background

In order to study the performance of the combined cycle power plant, understanding the theoretical background is significant to analyze, set up and verify the simulated model. Figure 2.1 illustrates a theory diagram to meet the research's solution, including CC process and potential technology, good simulated model, cost effectiveness analysis and PES value.

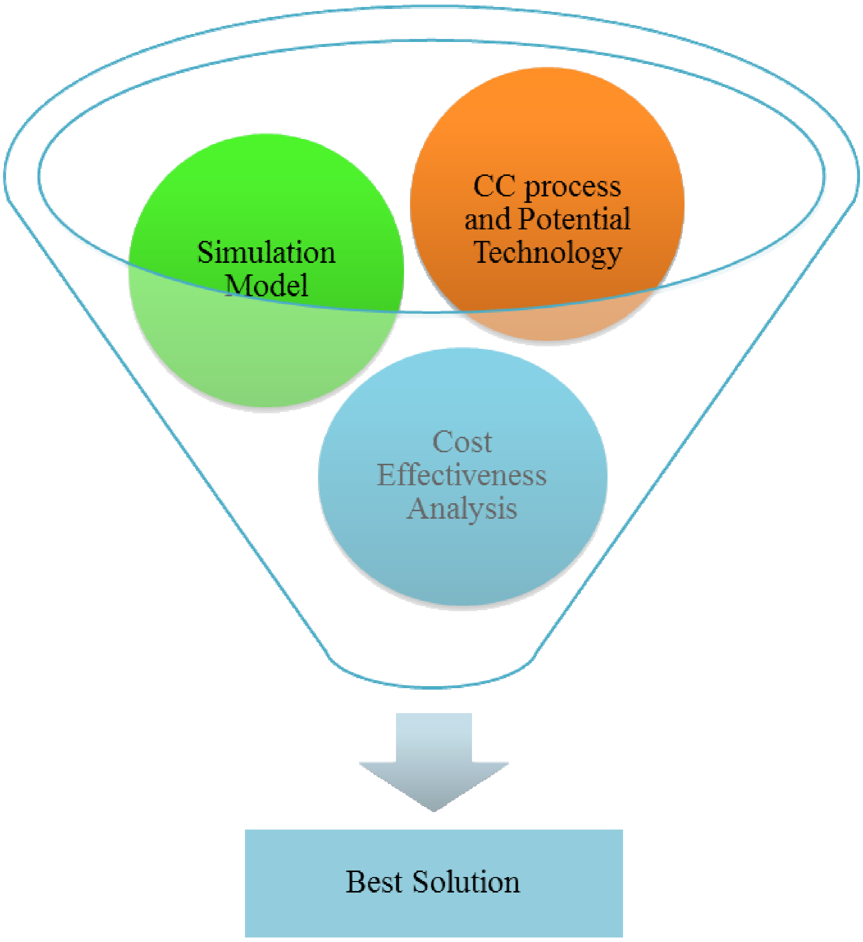


Figure 2.1: Theory diagram of the research

2.2 Combined Cycle System Principle

In order to calculate, develop and verify the simulated model of Bangpakong Combined Cycle Power Plant, there are many theories that should be considered. The basic consideration is the thermodynamic principle of the combined cycle power plant. These theories describe both the gas turbine system and steam turbine system. The main challenge in designing a combined cycle power plant is how to transfer gas turbine exhaust heat to the water/steam cycle to achieve optimum steam turbine output [2]. The simple combined cycle as shown in Figure 2.2 is helpful to comprehend easily in the concept and easily apply to complicated actual cycle that was developed for the simulate model that conform to actual components, systems, processes and operational parameters in the research.

To find out the potential technologies that are suitable and effective, the performance characteristics of the combined cycle were considered, as well as which factors and parameters affect performance, how to use that solution, and the limitations of each solution.

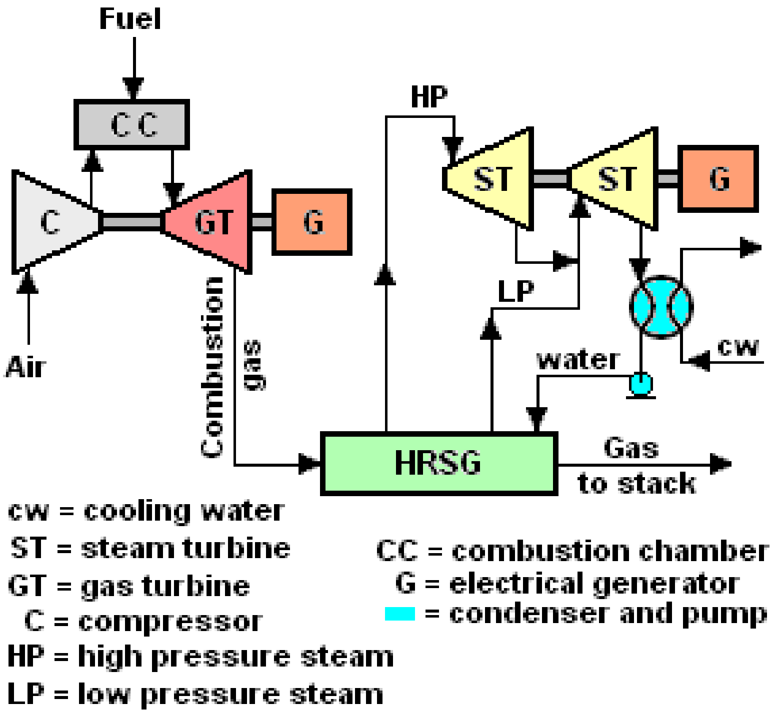


Figure 2.2: Schematic diagram of a typical combined cycle power plant

2.3 Degradation Analysis

2.3.1 Corrected Gas Turbine Generator Net Power Output

The gas turbine generator net power output will be corrected from actual conditions to the rated condition listed in Table B.1 (Appendix B)

$$CGNPO = GNPO \; x \prod_{i=1}^{12} Fip$$

Where

CGNPO is the corrected gas turbine generator net power output, MW

GNPO is the gas turbine generator net power output, MW

F1p is the factor to correct power from the measured compressor inlet temperature to the rated compressor inlet temperature

F1p = F1p (rated)/F1p (measured)

F2p is the factor to correct power from the measured compressor inlet relative humidity to the rated compressor inlet temperature relative humidity

F2p = F1p (rated)/F1p (measured)

F3p is the factor to correct power from the measured barometric pressure to the rated barometric pressure

F3p = F3p (rated)/F3p(measured)

F4p is the factor to correct power from the measured turbine shaft speed to the rated turbine shaft speed

F4p = F4p(rated)/F4p(measured)

F5p is the factor to correct power from the measured generator power factor to the rated generator power factor

F5p = 1 – (F5p (rated)-F5p(measured)/GNPO

F6p is the factor to correct power degradation = 1.0 (correction to be applied separately)

F7p is the factor to correct power from the measured inlet pressure drop to the rated inlet pressure drop

F7p = F7p(rated)/F7p(measured)

F8p is the factor to correct power from the measured exhaust pressure drop to the rated exhaust pressure drop

F8p = F8p(rated)/F8p(measured)

F9p is the steam injection correction factor = 1.0

F10p is the water injection correction factor = 1.0

F11p is the factor to correct power from the test fuel gas composition to the contract fuel gas composition

F11p = F11p(rated)/F11p(measured)

F12p is the factor to correct power from the measured fuel gas temperature to the rated fuel gas temperature

F12p = F12p(rated)/F12p(measured)

2.3.2 Corrected Gas Turbine Generator Net Heat Rate

The gas turbine generator net power output was corrected from actual conditions to the guaranteed conditions.

$$CGNHR = GNHRx \prod_{i=1}^{12} Fi_{HR}$$

Where

CGNHR is corrected gas turbine generator net heat rate, kJ/kWh

GNHR is the gas turbine generator net heat rate, kJ/kWh

F1HR is the factor to correct heat rate from the measured compressor inlet temperature to the rated compressor inlet temperature

F1HR = F1HR (rated)/F1HR (measured)

F2HR is the factor to correct heat rate from the measured inlet relative humidity to the rated compressor inlet relative humidity

F2HR = F1HR (rated)/F1HR (measured)

F3HR is the factor to correct heat rate from the measured barometric pressure to the rated barometric pressure

F3HR = F3HR (rated)/F3HR (measured)

F4HR is the factor to correct heat rate from the measured turbine shaft speed to the rated turbine shaft speed

F4HR = F4HR (rated)/F4HR (measured)

F5HR is the factor to correct heat rate from the measured generator power factor to the rated generator power factor

F5HR = 1 – (F5HR (rated)-F5HR (measured)/GNPO

F6HR is the factor to correct heat rate degradation = 1.0 (correction to be applied separately)

F7HR is the factor to correct heat rate from the measured inlet pressure drop to the rated inlet pressure drop

F7HR = F7HR (rated)/F7HR (measured)

F8HR is the factor to correct heat rate from the measured exhaust pressure drop to the rated exhaust pressure drop

F8HR = F8HR (rated)/F8HR (measured)

F9HR is the steam injection correction factor = 1.0

F10HR is the water injection correction factor = 1.0

F11HR is the factor to correct heat rate from the test fuel gas composition to the contract fuel gas composition

F11HR = F11HR (rated)/F11HR (measured)

F12HR is the factor to correct heat rate from the measured fuel gas temperature to the rated fuel gas temperature

F12HR = F12HR (rated)/F12HR (measured)

2.3.3 Gas Turbine Generator Net Power Output Degradation

Gas turbine generator net power output degradation was calculated from the corrected gas turbine generator net power output and the baseline corrected gas turbine generator net power. A positive NOI indicates that the current level of performance is better than the guaranteed performance.

$$NOI = \frac{OPT - CGO}{CGO} \times 100$$

Where:

NOI is gas turbine net power output improvement (degradation), %

OPT is output performance test (corrected), MW

CGO is baseline gas turbine net power output from Table B.2 corrected for the expected degradation from the power output degradation

CGO = GO x (1 – Odeg %/100)

Where GO is guaranteed output which is 98.786 MW for GT-42 and assuming GT-41’s guarantee output is equal to GT-42

Odeg % is obtained by linear interpolation from the power output degradation shown in Table B.2. Factored fired hours interpolated in Table B.2 in Appendix B are factored fired hours since the baseline test.

2.3.4 Gas Turbine Generator Heat Rate Degradation

Gas turbine generator heat rate degradation was calculated from the corrected gas turbine generator heat rate and the baseline corrected gas turbine generator net heat rate. A positive NHRI indicates that the current level of performance is better than the guaranteed performance.

$$NHRI = \frac{CGHR - HRPT}{CGHR} \times 100$$

Where

NHRI is gas turbine net heat rate improvement (degradation), %

HRPT is heat rate performance test (corrected), MW

CGHR is baseline gas turbine net heat rate from Table B.2 corrected for the expected degradation from the heat rate degradation

CGHR = GHR x (1 + Odeg %/100)

Where GHR is guaranteed output which is 11,590 kJ/kWh for GT-42 and assuming GT-41's guarantee heat rate is equal GT-42

Odeg % was obtained by linear interpolation from the heat rate degradation in Table B.2. Factored fired hours interpolated shown in Table B.2 in Appendix B are factored fired hours since the baseline test.

2.4 Primary Energy Saving

PES in comparison with the separate production of heat and power is calculated using the reference values. The amount of primary energy savings (PES) was calculated based on the methodology described in the EU directive which states that the efficiency of the combined cycle gas turbine with heat recovery shall be at least 80%. Equations 2.1 and 2.2 are used for PES calculation:

$$PES = \left(1 - \frac{1}{\frac{H_\eta}{REFH_\eta} + \frac{E_\eta}{REFE_\eta}}\right) \quad if \quad \eta < 80\% \qquad (2.1)$$

$$PES = \left(1 - \frac{1}{\frac{CHPH_\eta}{REFH_\eta} + \frac{CHPE_\eta}{REFE_\eta}}\right) \quad if \quad \eta \geq 80\% \qquad (2.2)$$

Where:

$H\eta$ is the total heat efficiency, the total heat product divided by the total fuel

$E\eta$ is the total electrical efficiency, the total electricity product divided by the total fuel

$CHPH\eta$ is the heat efficiency of combined heat and power production defined as annual useful heat output divided by fuel input used to produce the sum of useful heat output and electricity from combined heat and power

$$CHPH_\eta = \frac{q_{CHP}}{f_{CHP}}$$

$CHPE\eta$ is the electricity efficiency of the combined heat and power defined as annual electricity from the combined heat and power divided by the fuel input used to produce the sum of useful heat output and electricity from the combined heat and power.

$$CHPH_{\eta} = \frac{p}{f_{CHP}}$$

q_{chp} = CHP useful heat energy

= $q - q_{non\text{-}chp}$

f_{chp} = CHP fuel energy

= $f - f_{non\text{-}chp}$

q = Total useful energy

$q_{non\text{-}chp}$ = Non-combined useful heat energy

f = Total fuel energy

$f_{non\text{-}chp}$ = Non-combined fuel energy

p = Total electrical/mechanical energy

REF Hη is the efficiency reference value for heat production as shown in Table 2.1

REF Eη is the efficiency reference value for electricity production as shown in Table 2.1

Table 2.1 Efficiency reference value for heat production and electricity production

Type of fuel	***REF Eη***	***REF Hη***
Natural Gas	45 %	85 %
Coal	40%	80%

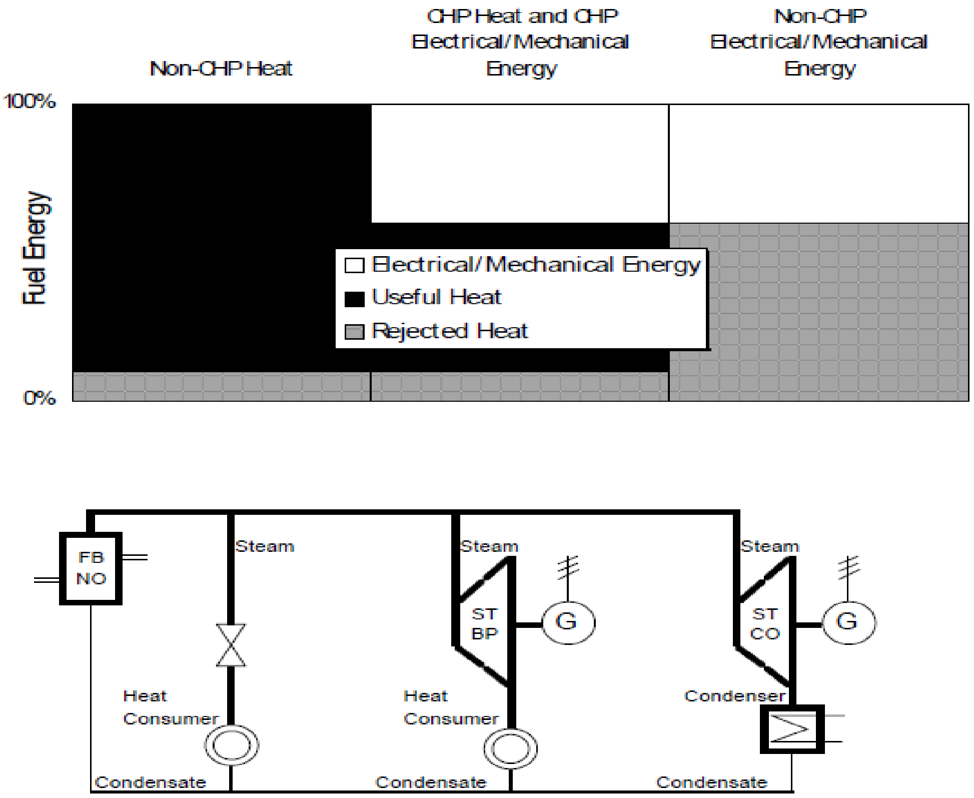


Figure 2.3 Subdivision of a CHP Plant in Combined and Non-Combined Processes

2.5 Simulation Model (Gate Cycle)

The Gate Cycle is a powerful computer program used for evaluating the performance of existing and conceptual power plant systems at design and off-design points. It is flexible and fully features heat balance modeling software. Gate Cycle combines an intuitive, graphical user interface with detailed analytical models for the thermodynamic, heat-transfer and fluid-mechanical processes within power plants to allow users to run design and simulation studies of any complexity [9]. It is used to predict performance for combined-cycle power plants, conventional steam plants, cogeneration systems, combined heat-and-power plants, advanced gas turbine cycles, and many other energy systems. With the flexibility to incorporate user defined equations and tables, to simulate control loops, and to vary an unrestricted number of model parameters in a regression routine, Gate Cycle is used to optimize a plant’s design or to simulate the operation of an existing plant under specific conditions.

Gate Cycle models are extremely flexible, allowing an indefinite number of calculation cases to cover variations in design parameters as well as plant performance under "off-design" conditions. When the simulate models are performed, the mass and energy balances are solved by a sequential modular algorithm for both the overall system as well as all individual components, and detailed reports generate for each. If the heat balance cannot be solved, an error file is generated, allowing the user to identify the source of the problem and correct the model accordingly. Figure 2.4 shows the data input and output of Gate Cycle mode, and specifies the required inputs and the generated model output.

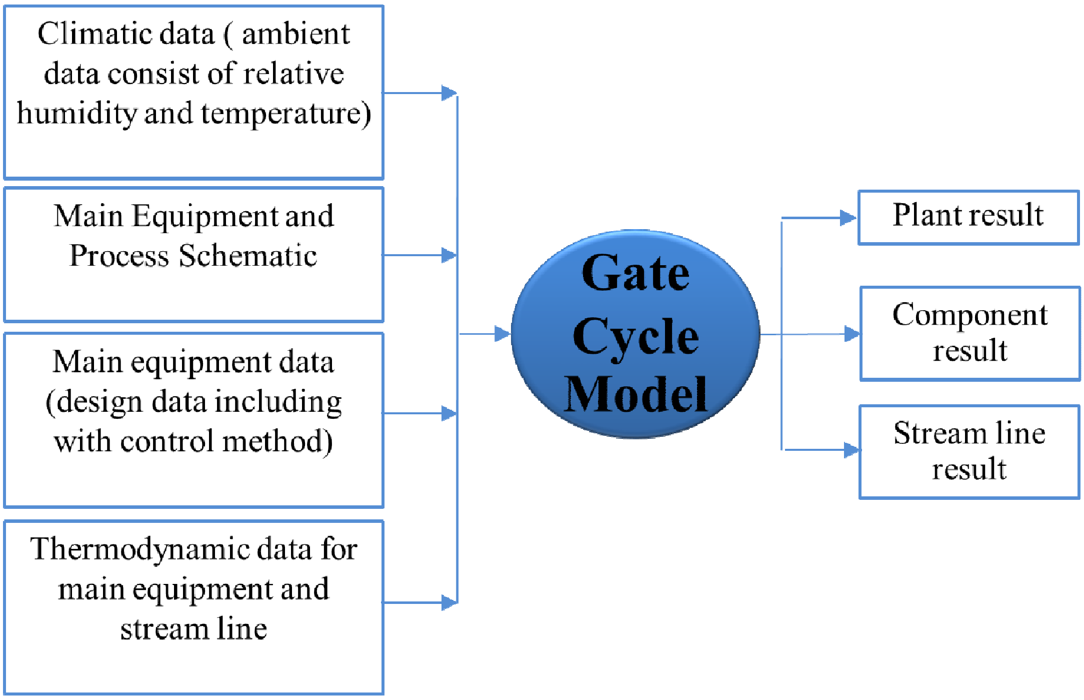


Figure 2.4 Model input and output

2.6 Cost Effectiveness and Feasibility

Cost-effectiveness analysis (CEA) is an economic form for the comparison of the alternative projects with the same objectives in which it is difficult to value an efficient selection. Cost-effectiveness ratio indicates the best project or the first priority project. It can identify maximize the production on given cost or minimize the cost on given amount of produced value. The cost effectiveness of this project can be defined as follows:

$$Cost\ effectiveness\ ratio = \frac{Investment\ cost\ (\$)}{Augmented\ annual\ output\ (MWh)}$$

The cost effectiveness is presented in terms of the ratio of the investment cost and augmented annual output. It describes the system that can obtain the minimum amount of investment cost on a given augmented annual output is the best option.

Figure 2.5 shows an example of summary cast flow and elements commonly used in engineering investment projects. There are many variables are involved in the estimation of cash flows, and many individuals and departments participate in the process.

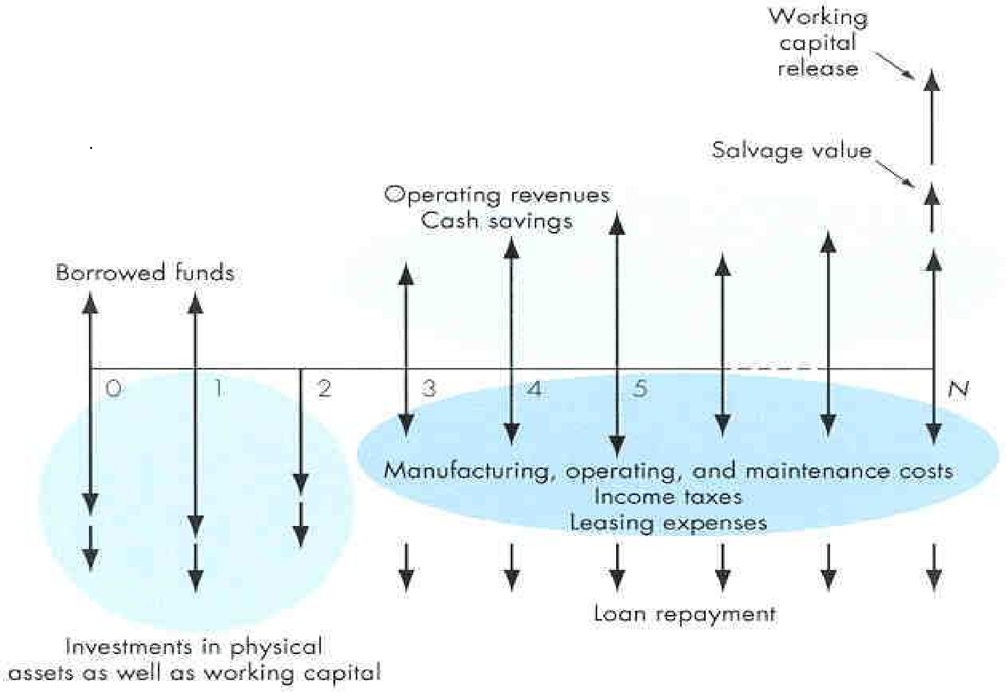


Figure 2.5: Types of cash flow elements used in project analysis

Subsequently, the net cash flow from the project is

Net cash flow = Cash inflow – Cash outflow

The cash flow element can be grouped into three areas, which are the cash flow elements related to operations, investment activities, and project finance. A common-used format for presenting a cash flow statement is presented in Figure 2.6.

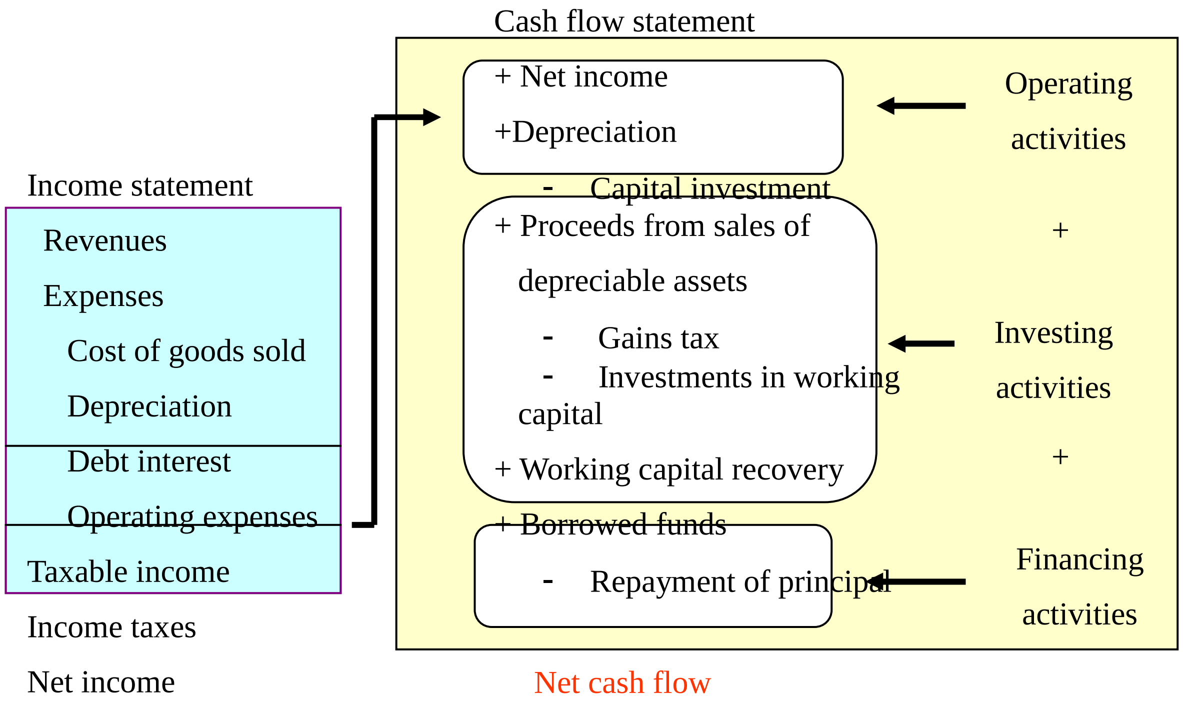


Figure 2.6: A common-used format for presenting a cash flow statement

CHAPTER 3

METHODOLOGY

3.1 Degradation Analysis

Bangpakong Combined Cycle Power Plant Block 4 has been generating electricity in commercial use over the last several years. Degradation study provides the result to select a location, which should be the first priority improvement.

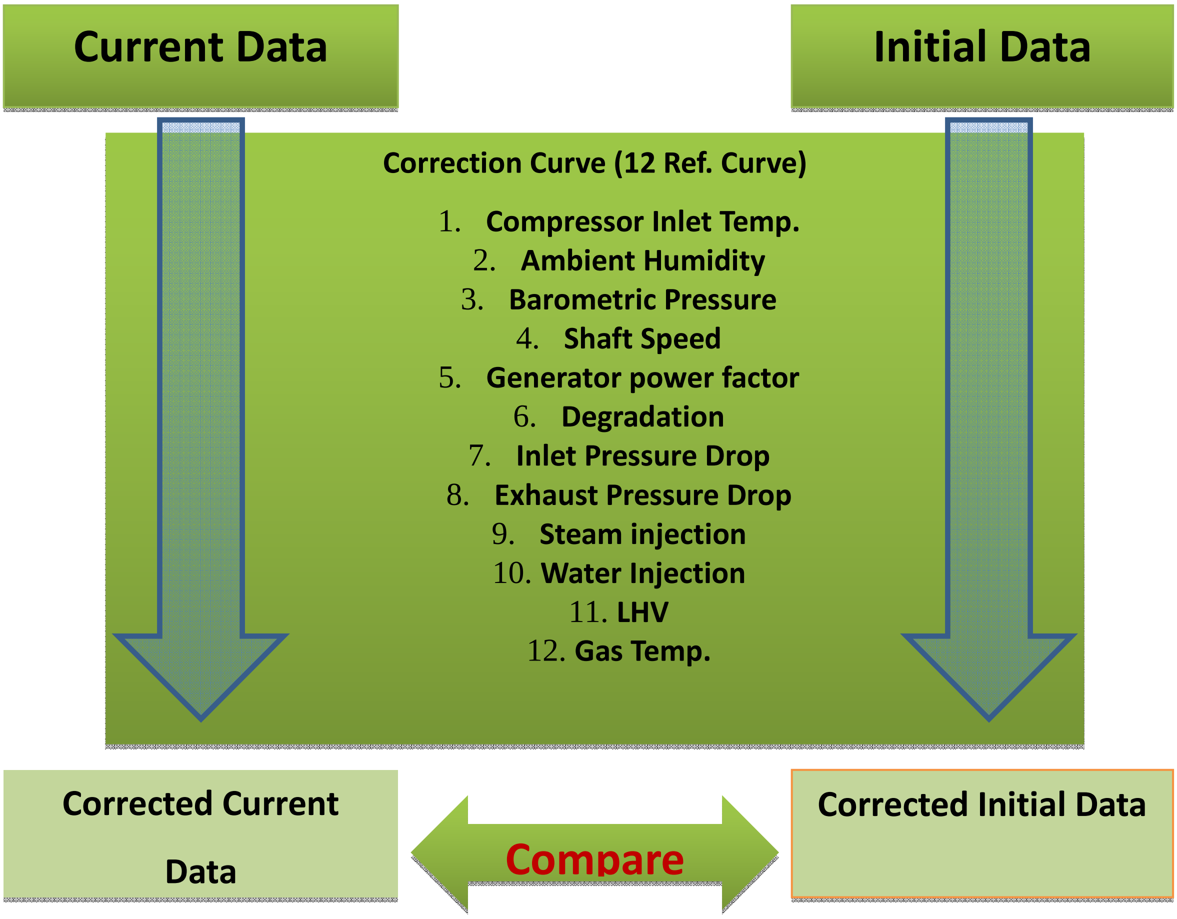


Figure 3.1: Methodology for degradation analysis

Figure 3.1 shows a procedure for degradation analysis, performance test value listing are considered the main parts of BPK-CC Block 4 is prepared for this part. Current data and initial data are recorded at different conditions, therefore both data are corrected to the same ambient condition (32.2 ^{o}C, average temperature of Bangpakong Power Plant) by using Correction Factor Curve of GE Manufacture. There are seven reference corrections curves: compressor inlet temperature, ambient humidity, shaft speed, inlet pressure drop, exhausts pressure drop, LHV and gas temperature. All performance test data are based on the base load of the Bangpakong Combined Cycle Power Plant (100% load or full load). Current performance test data of October 2010 are used in this study. Performance of power plant was compared to analyzed degradation of combined cycle power plant.

3.2 Gas Turbine Inlet Cooling Analysis and Cost Effectiveness

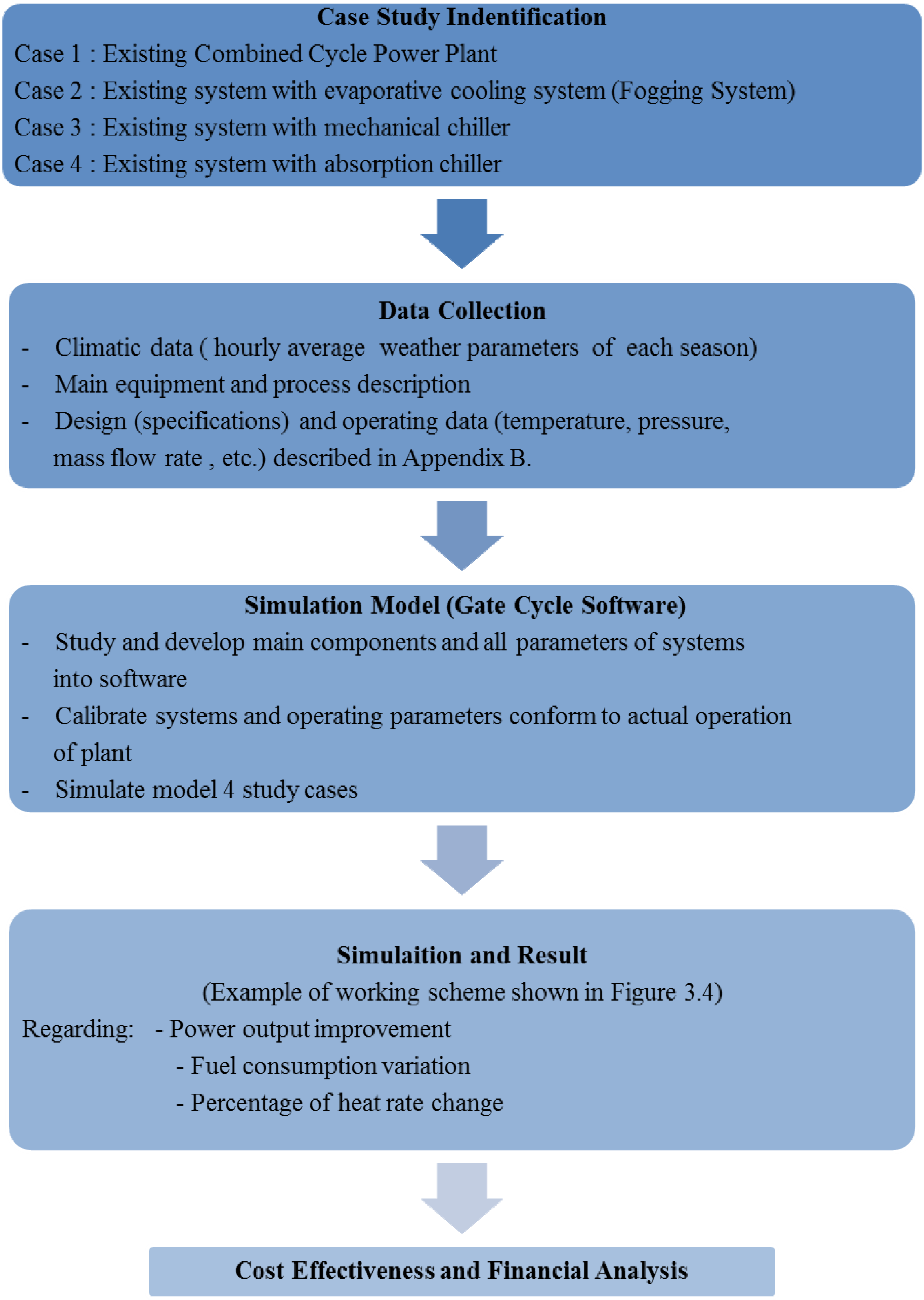
The main methodologies are presented in Figure 3.2.

3.2.1 Firstly, the study cases, which are existing CC, existing CC with evaporative cooling system (high pressure fogging system), existing CC with mechanical chiller and existing CC with absorption chiller were selected and identified for this research.

3.2.2 Secondly, data collection was implemented carefully for minimizing errors.

(1) Climate data: the combined cycle power plant consists of gas turbine and heat recovery steam generation in which the gas turbine's behavior strongly depends on weather conditions. Therefore, it is significant to prepare weather parameters (temperature and relative humidity) carefully in order to characterize a particular site climate. For this project, the history of climate data of Bangpakong in 2010, which was recorded every 10 minutes at the site was selected, arranged into seasonal averages of hourly weather parameters and used to evaluate the climate as an average year, as represented in Appendix A. It is characterized by a set of double points of ambient temperature and relative humidity.

(2) The main equipment were implemented for the simulated model of the existing plant, which is used as the reference of comparison.



Case Study Indentification

Case 1 : Existing Combined Cycle Power Plant
Case 2 : Existing system with evaporative cooling system (Fogging System)
Case 3 : Existing system with mechanical chiller
Case 4 : Existing system with absorption chiller

Data Collection

- Climatic data (hourly average weather parameters of each season)
- Main equipment and process description
- Design (specifications) and operating data (temperature, pressure, mass flow rate , etc.) described in Appendix B.

Simulation Model (Gate Cycle Software)

- Study and develop main components and all parameters of systems into software
- Calibrate systems and operating parameters conform to actual operation of plant
- Simulate model 4 study cases

Simulaition and Result

(Example of working scheme shown in Figure 3.4)

Regarding: - Power output improvement
- Fuel consumption variation
- Percentage of heat rate change

Cost Effectiveness and Financial Analysis

Figure 3.2: Methodology for gas turbine cooling system analysis

(3) Design and operating data: In order to operate for long in commerce, it is important to properly prepare the specifications, design and current operating data, temperature, pressure, mass flow rate, setting point of equipment, etc. Bangpakong combined cycle power plant has been commercially used for over 20 years, therefore some setting points are changed and applied to current operations. The equipment is also operated at lower performance.

3.2.3 Thirdly, Gate cycle software by GE manufacturer is used to transform physical engineering characteristics of the plant into a simulation model. Main sets of equipment of the existing plant was developed, including the design and operating data as shown in Appendix B, then they were connected to the model. All specifications and setting points of steam lines were identified. Each sub-loop needs to be run for checking errors before it is connected to the other sub-loop systems. It was necessary to check errors for loop system because combined cycle plant is totally complex system, changing each setting point affects other loops. It is difficult to adjust the system when errors happen without checking sub-loop errors. The next part was calibration of the simulation model of existing plant to conform to actual operation. After the simulation model was validated, three alternative options were applied in a model for the next part.

3.2.4 For Clearness in the simulation step, an average day was calculated for each season, consisting of 24 temperatures and relative humidity hourly points. Each one is the mean value of all average data for an hour for all the days of the season. Since there are 3 seasons and 3 systems, 288 points were studied (3 seasons x 3 systems x 24 h + 3 seasons x 24 h of NO additional system). Figure 3.4 shows an example of how the simulation study (power output, fuel consumption and heat rate) was made. One of the 3 seasons and 3 systems (evaporative system in summer) was selected as example. Input data were arranged as an average day, in particular, temperature and relative humidity. Output data were subsequently calculated using Bangpakong combined cycle simulation model. Since the use of cooling systems for partial CC loads is not generally recommended, a constant full load was considered in this study.

The diagram of the working scheme is shown in Fig. 3.4. The procedure is as follows:

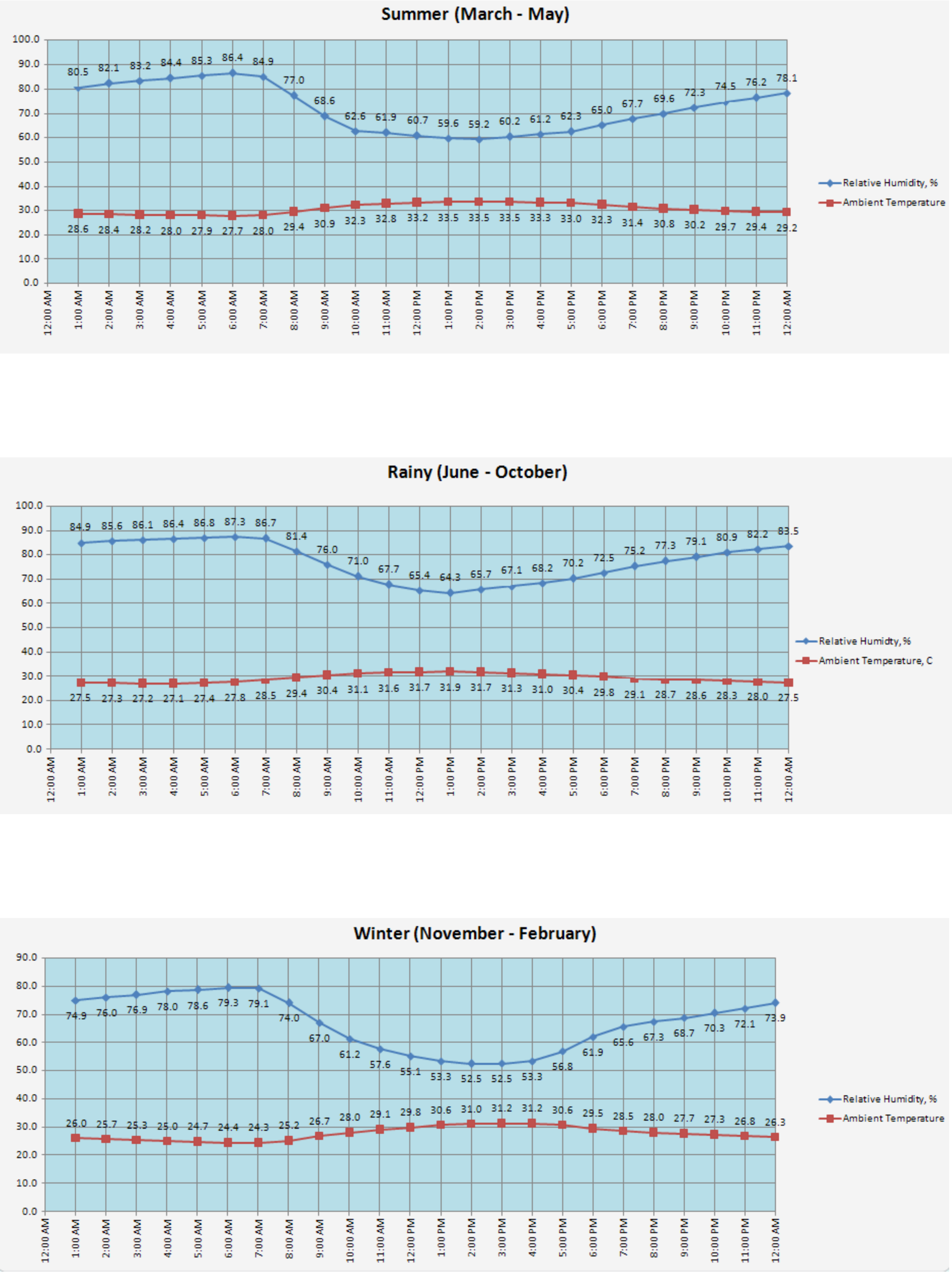


Figure 3.3: Average temperature and relative humidity of 3 seasons

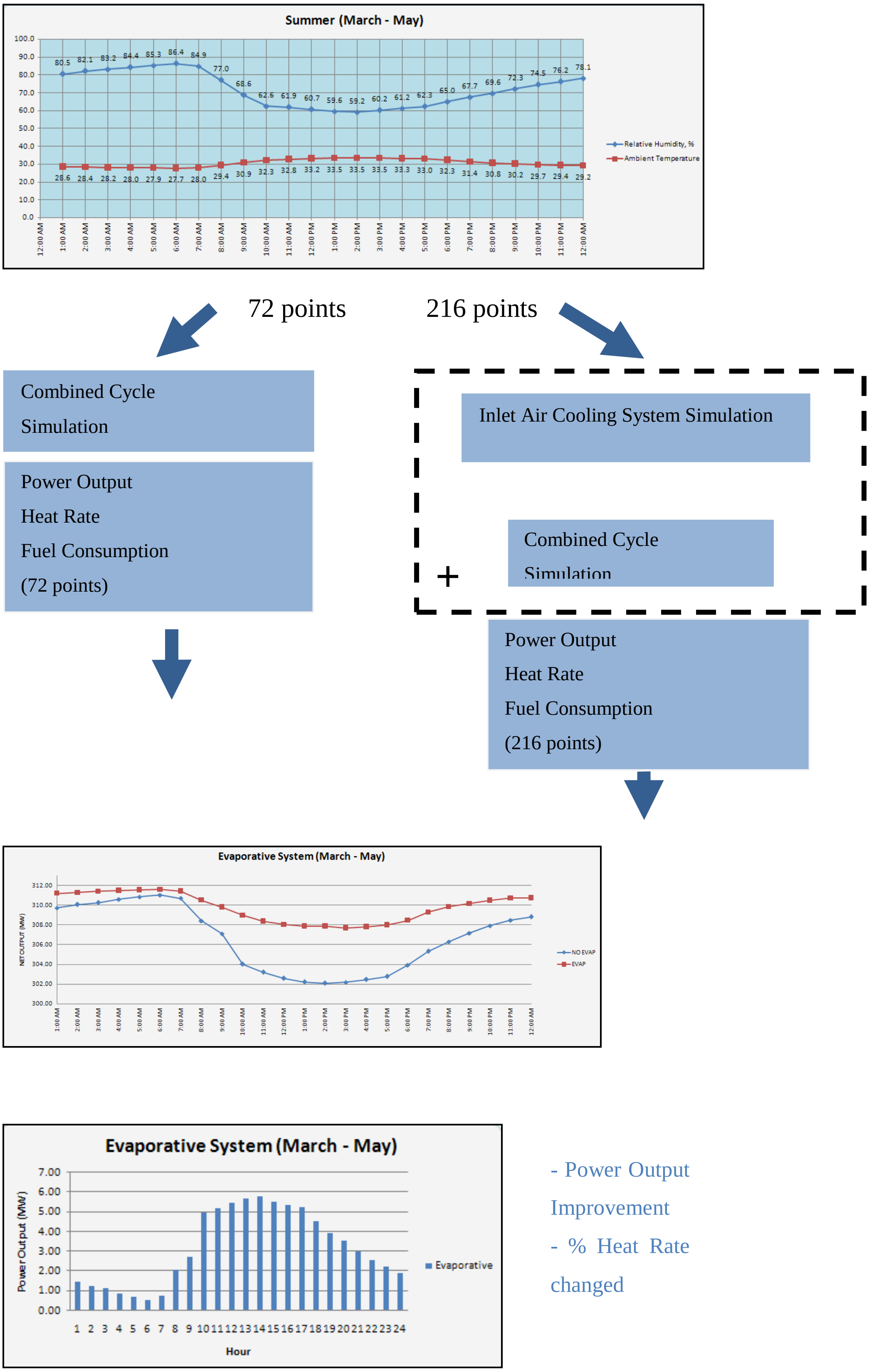


Figure 3.4: Working scheme of simulation study applied to evaporative system in summer as example

1) The climate data of an average day of each season were calculated and plotted, as shown in Figure 3.3. Twenty-four pairs of data (temperature and relative humidity) represent an average day. Seventy-two points completely represent the site weather.

2) Simulation of the combined cycle power plant performance without the air inlet cooling system was made, according to historical climate data. Seventy-two variations of input data details in Section 4.2.1 generated seventy-two thermodynamic balances. The results were recorded to be the base of performance comparison: power output improvements, fuel consumption variation and percentage of heat rate change.

3) Simulations of the combined cycle power plant performance with three air inlet cooling systems: high pressure fogging system, mechanical chiller, absorption chiller. Similar to the simulation of the combined cycle power plant performance without the air inlet cooling system, two hundred and sixteen variations (72 x 3 systems) of input data are clearly detailed in Section 4.2.1 generating two hundred and sixteen thermodynamic balances. The results were plotted into each base for the next step.

4) Comparison of the previous results in order to explain power output improvements, fuel consumption variation and percentage of heat rate change for each hour.

3.2.5 However in the last step, the selection of the best alternative decision cannot be completed without consideration of finance and energy utilization. For clearness decision, cost effectiveness and feasibility were used to analysis the best solution of the BPK plant. Cost effectiveness analysis compares the cost of inlet cooling system effect to plant performance. Cost Effectiveness is determined as investment cost divide by the annual augmented power output (MWh). Investment cost of electricity chiller and absorption chiller details in APPENDIX E. Assumption of investment cost of high pressure fogging system is prepared by:

- Equipment cost = 100$/RT [10]
- Installation and piping = 5% equipment cost
- Engineering & site management = 5% equipment cost

Nevertheless, assumption of investment cost and building modification are not considered in this research.

Table 3.1: Assumption for feasibility analysis

	Description	Unit	Fogging System	Mechanical Chiller	Absorption Chiller
1	Annual Increased Net Power Output	MWh	20,779	42,447	53,695
2	Annual Increased Fuel Consumption	MMBTU	262,210	1,252,822	1,252,822
3	Plant Factor		70.00%		
4	Exchange Rate	฿/$USD	31		
5	Electricity Price *	฿/kWh	2.7497		
6	Fuel Unit Price *	฿/MMBTU	175		
7	O&M Cost for Inlet Cooling System, esc 0%****	฿ per year	7,143	3,158,400	1,748,400
8	Cooling Load	RT	1,420	9,400	9,400
9	Water Unit Price	฿/Cu.m	53.0	23.5	23.5
10	Water Used	Cu.m	22,726	938,045	938,045
11	Investment		EGAT 100 %		
12	Weighted Average Cost of Capital raised for additional fund (WACC)		9.10%		
13	Investment	$	149,105	16,303,226	18,129,032
14	Tax Rate		30.00%		
15	Useful life	years	8	8	8

Note

* Short-Run Marginal Cost Average Analysis, EGAT report, July 9,2010

*** Make up water to cooling tower is 0.014m^3 / hr – RT

**** Fogging: 50 man-hours of maintenance per year [12], average salary 30000 ฿/month person

Mechanical Chiller: 28 ฿ / RT / month

Absorption Chiller: 15.5 ฿ / RT / month

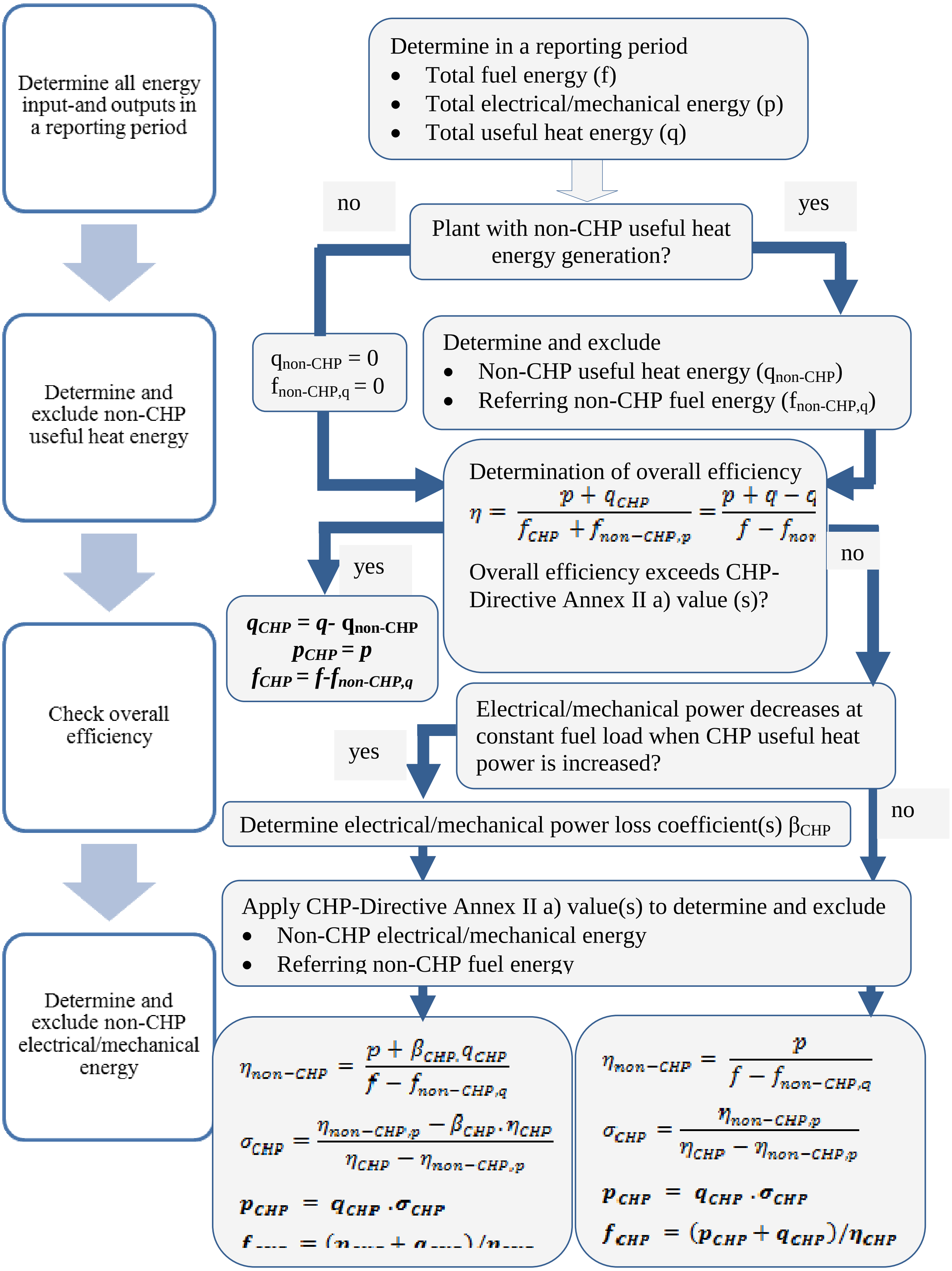
The feasibility analysis is most important for determining the investment that is expected for a return on the investment to be received in the future. The subject is whether the amount of a forecasted future cash flow is large enough to justify investing the proposed funds in the future. Table 3.1 shows the assumptions for analyzing the feasibility of this project.

3.3 Primary Energy Saving PES

The determination of energy utilization and finance for alternative system consist of two parts as follows.

Primary energy saving (PES) used generally to be a regulatory standard for energy efficient utilization of Cogeneration plant or Combined Heat and Power Plant. The amount of primary energy saving (PES) is calculated based on methodology purpose in EU directive. A year is a period of time used for determination of data for this research. Figure 3.5 illustrates the principle of CHP determination according to EU directive. There are four steps in determination. The first step is determination of all energy input and output in the considered period. The second step is determination useful heat energy and non-CHP useful heat energy then checks overall efficiency of plant. The power loss efficiency are considered when the overall efficiency is lower than the efficiency specify in EU directive in which the combined cycle gas turbine with heat recovery efficiency standard is 80%. The energy loss coefficient defines as relation between generation of useful heat energy and electrical energy/power loss. The electrical power loss is typical for extraction-condensing or extraction-backpressure steam turbines by extracting the working fluid (steam or exhaust gas) from the turbine for generation of useful heat energy as the same fuel input. The last step is to determine non-CHP electric energy.

After all the required energy for PES calculation has been generated, then PES is considered for which the cogeneration is considered highly efficient to ensure at least 10% savings of primary energy (fuel) as compared to separate generation of thermal and electric energy. The energy conservation indicator of the combined generation is calculated by the formula given in Chapter 2.



Determine all energy input-and outputs in a reporting period

Determine and exclude non-CHP useful heat energy

Check overall efficiency

Determine and exclude non-CHP electrical/mechanical energy

Determine in a reporting period
- Total fuel energy (f)
- Total electrical/mechanical energy (p)
- Total useful heat energy (q)

Plant with non-CHP useful heat energy generation?

$q_{non\text{-}CHP} = 0$
$f_{non\text{-}CHP,q} = 0$

Determine and exclude
- Non-CHP useful heat energy ($q_{non\text{-}CHP}$)
- Referring non-CHP fuel energy ($f_{non\text{-}CHP,q}$)

Determination of overall efficiency

$$\eta = \frac{p + q_{CHP}}{f_{CHP} + f_{non-CHP,p}} = \frac{p + q - q}{f - f_{non}}$$

Overall efficiency exceeds CHP-Directive Annex II a) value (s)?

$$q_{CHP} = q - q_{non\text{-}CHP}$$
$$p_{CHP} = p$$
$$f_{CHP} = f - f_{non\text{-}CHP,q}$$

Electrical/mechanical power decreases at constant fuel load when CHP useful heat power is increased?

Determine electrical/mechanical power loss coefficient(s) β_{CHP}

Apply CHP-Directive Annex II a) value(s) to determine and exclude
- Non-CHP electrical/mechanical energy
- Referring non-CHP fuel energy

$$\eta_{non-CHP} = \frac{p + \beta_{CHP}.q_{CHP}}{f - f_{non-CHP,q}}$$

$$\sigma_{CHP} = \frac{\eta_{non-CHP,p} - \beta_{CHP}.\eta_{CHP}}{\eta_{CHP} - \eta_{non-CHP,p}}$$

$$p_{CHP} = q_{CHP}.\sigma_{CHP}$$

$$f_{CHP} = (p_{CHP} + q_{CHP})/\eta_{CHP}$$

$$\eta_{non-CHP} = \frac{p}{f - f_{non-CHP,q}}$$

$$\sigma_{CHP} = \frac{\eta_{non-CHP,p}}{\eta_{CHP} - \eta_{non-CHP,p}}$$

$$p_{CHP} = q_{CHP}.\sigma_{CHP}$$

$$f_{CHP} = (p_{CHP} + q_{CHP})/\eta_{CHP}$$

Figure 3.5: Determination Principles [11]

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Degradation Analysis

The main challenge in a combined cycle plant is how to transfer gas turbine exhaust heat to the water/steam cycle to achieve the optimum steam turbine output. The focus was on the heat recovery steam generator (HRSG) in which the heat transfer between gas cycle and the water/steam cycle take place [2]. Table 4.1 represent percentage of degradation of each part in Bangpakong combined cycle power plant. Generated power output of gas turbine BG 41 decrease 8% and the efficiency highly reduce 15.31%. BG 42 has percentage of degradation less than BG 41 because this gas turbine has been upgraded on GE‘s uprate program in 2005. Steam Turbine and HRSG performance is the function of energy transfer of HRSG and Condenser. As Table 4.1, percentage of degradation HRSG 41, HRSG 42 and condenser is 5%, 7.79% and 9.82% respectively. However degradation of all heat exchangers has a small effect on steam turbine output and efficiency which reduce performance of 1.88% and 2.57% respectively. Therefore the performance improvement is focus on gas turbine improvement.

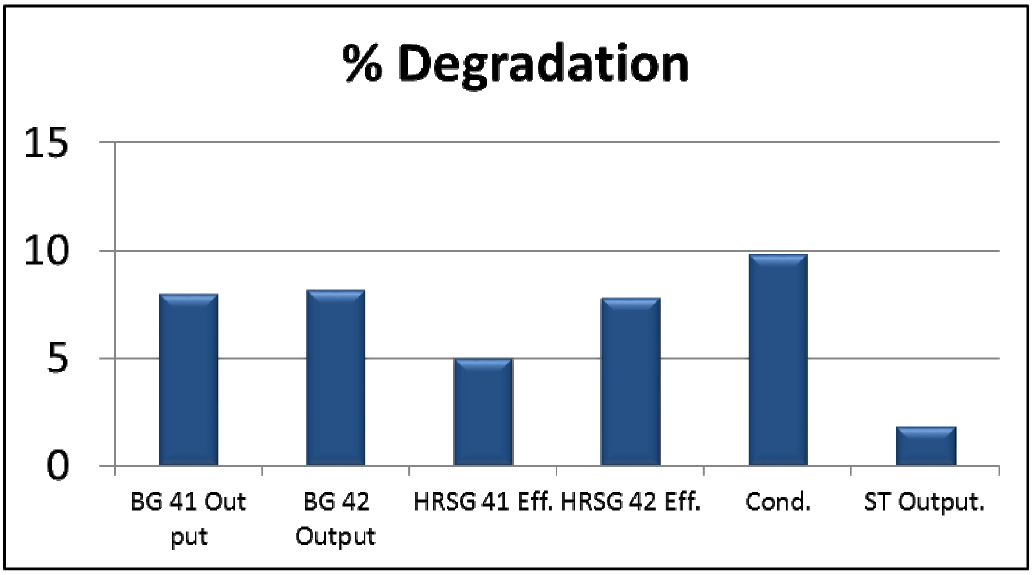


Figure 4.1 Percentage of degradation

Table 4.1 Comparison of performance of BPK-CC Block 4

	Design /Initial value	**Current value**	**% degradation**
BG-41 Gas Turbine Output (MW)	106.50	97.88	-8.00
BG-41 GT Gross Efficiency, (%)	33.5	28.37	-15.31
BG-41 Auxiliary consumption (MW)	.31	0.33	-6.06
BG-42 Gas Turbine Output (MW)	106.72	97.74	-8.41
BG-42 GT Gross Efficiency, (%)	28.48	28.36	-0.42
BG-42 Auxiliary consumption (kW)	.295	0.33	-11.86
Steam Turbine Output (MW)	109.99	107.92	-1.88
ST Gross Efficiency (%)	36.19	35.26	-2.57
ST Auxiliary Consumption (MW)	4.5	4.13	8.22
Gross Output (MW)	323.21	303.54	-6.08
Gross Efficiency (%)	46.70	44.01	-5.76
Total Auxiliary Consumption (MW)	5.105	4.79	6.17
HRSG 41 EFF (%)	80.71	76.61	-5
HRSG 42 EFF (%)	82.12	75.72	-7.79
Energy Transfer of Condenser (MW)	207.68	187.28	-9.82
Condenser Press. (mm.Hg)	64.51	57.04	
BG – 41 Stack Temp. (^{o}C)	542.05	554.44	
BG – 42 Stack Temp. (^{o}C)	541.17	553.47	

4.2 Gas Turbine Inlet Cooling Analysis

This part represents the study of three types of gas turbine inlet cooling system which affect the performance of the Bangpakong Combined Cycle Power Plant. The simulation model for research analysis process was created, applied and solved on Gate Cycle software. The main study was to find the result of additional cooling systems regarding power output, heat rate and power consumption, then these results were used to analyze the best system by using cost effectiveness.

4.2.1 Simulation Model and Results

Case 1: Existing Combined Cycle Power Plant

The existing Banpakong Combined Cycle Power Plant simulation model is shown in Figure 4.2. It was developed by adding main components of the plant with specification of equipments, as detailed in Table C in Appendix C, be linked and specified by steam lines to be an existing plant model. After completing all individual components connection and edition, thermodynamic properties of operating condition and specification of each component are input based on performance test data which is full load and steady operation onsite. Details of simulation result are shown in Appendix C. The next part, the model was run to examine the outputs and then compare the outputs against the performance test data for validation and accuracy comparison.

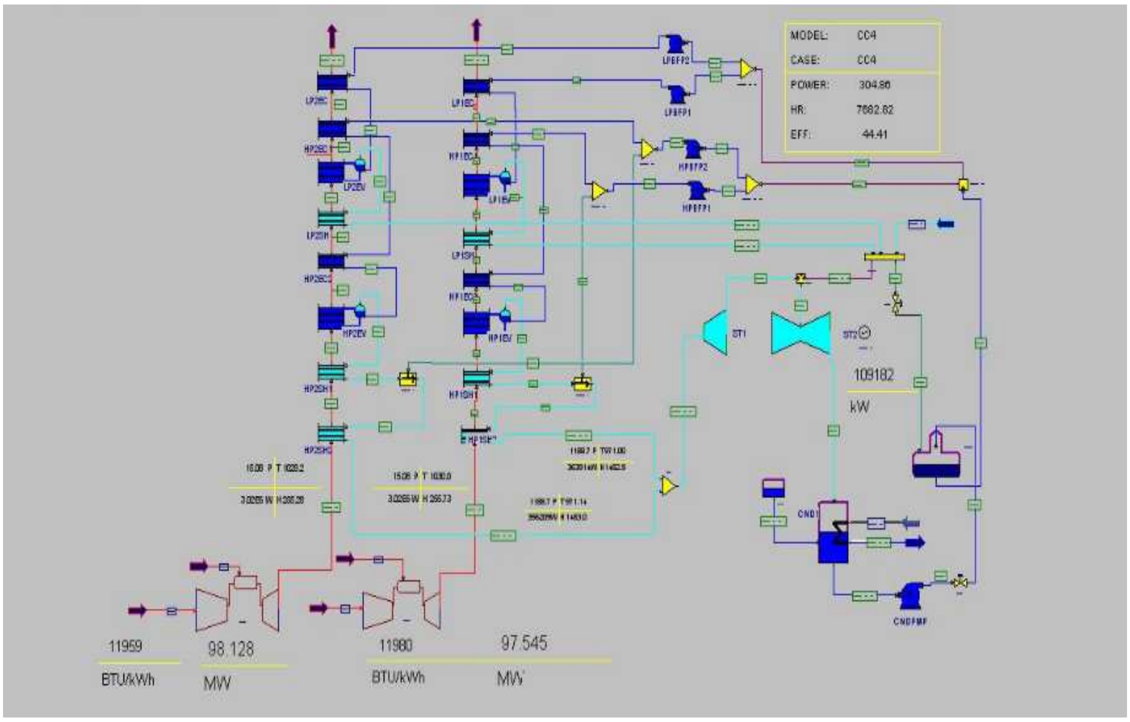


Figure 4.2 Bangpakong Combined Cycle Power Plant Block 4 Model

Table 4.2 presents a comparison of the simulation results and the performance test data. Thermodynamic properties, such as temperature, pressure and enthalpy of the mode are all presented with similar values as the existing operations. More details are in

Appendix B. Energy balance and heat balance are in small errors. Therefore, it can be seen that the simulation model corresponds to the actual operation of an existing plant.

Table 4.2 Comparison of simulation result with operating data

	Description	Simulation Result	Operating Data
	Ambient Temperature (C)	32.78	32.78
	Relative Humidity (%)	62.473	62.473
GT 41	Power Output (MW)	97.545	97.541
	Heat Rate (kJ/kWh)	12,640	12,639
	Efficiency (%)	28.418	28.482
	Exhaust Temperature (C)	554.44	554.44
GT 42	Power Output (MW)	98.128	98.128
	Heat Rate (kJ/kWh)	12,618	12,617
	Efficiency (%)	28.530	28.530
	Exhaust Temperature (C)	553.44	553.47
ST	Power Output (MW)	109.2	108.9
	High Pressure Main Steam Temp. (C)	522	522
	Low Pressure Steam Temp. (C)	233.6	233.6
	Cooling Water Temp. (C)	29.38	29.38

Table 4.3 Input variable parameters in simulation model

Description	Used data
GT ambient air temperature	As indicated Table A in Appendix A
GT relative humidity	As indicated Table B in Appendix A
Condenser cooling water temperature	Assume equal ambient air temperature

After an existing plant model was developed and calibrated to conform to actual operations, Input variable parameters of Bangpakong combined cycle model, as shown in Table 4.3, were keyed into the model. With the profiles of seasonably average of hourly temperature and relative humidity, a simulation model performed and generated heat balance result for each weather condition (72 running = 24 hr. x 3 season).

The results, which are the power output, fuel consumption and heat rate are presented in Figures 4.3, 4.4 and 4.5 respectively. The hourly performance corresponds to gas turbine behavior by varying hourly temperature and humidity of each. Lower temperature generate higher power output. Table 4.4 shows the maximum and minimum of variation of performance of each season. All results will be the base of study in air inlet cooling system. An existing plant generates the maximum power output of 316.04 MW in winter and minimum value of 302.09 MW in summer. This plant needs maximum fuel consumption of 2.59 x10^9 kJ/h in winter and minimum value of 2.46 x10^9 kJ/h in summer.

Table 4.4 Maximum and minimum of an existing plant's performance

	Summer		Rainy		Winter	
	Max.	Min.	Max.	Min.	Max.	Min.
Power Output (MW)	311.05	302.09	311.94	304.67	316.04	305.60
Fuel Consumption (10^9kJ/h)	2.54	2.46	2.55	2.48	2.59	2.49
Heat Rate (kJ/kWh)	8,171	8,142	8,173	8,153	8,183	8,148

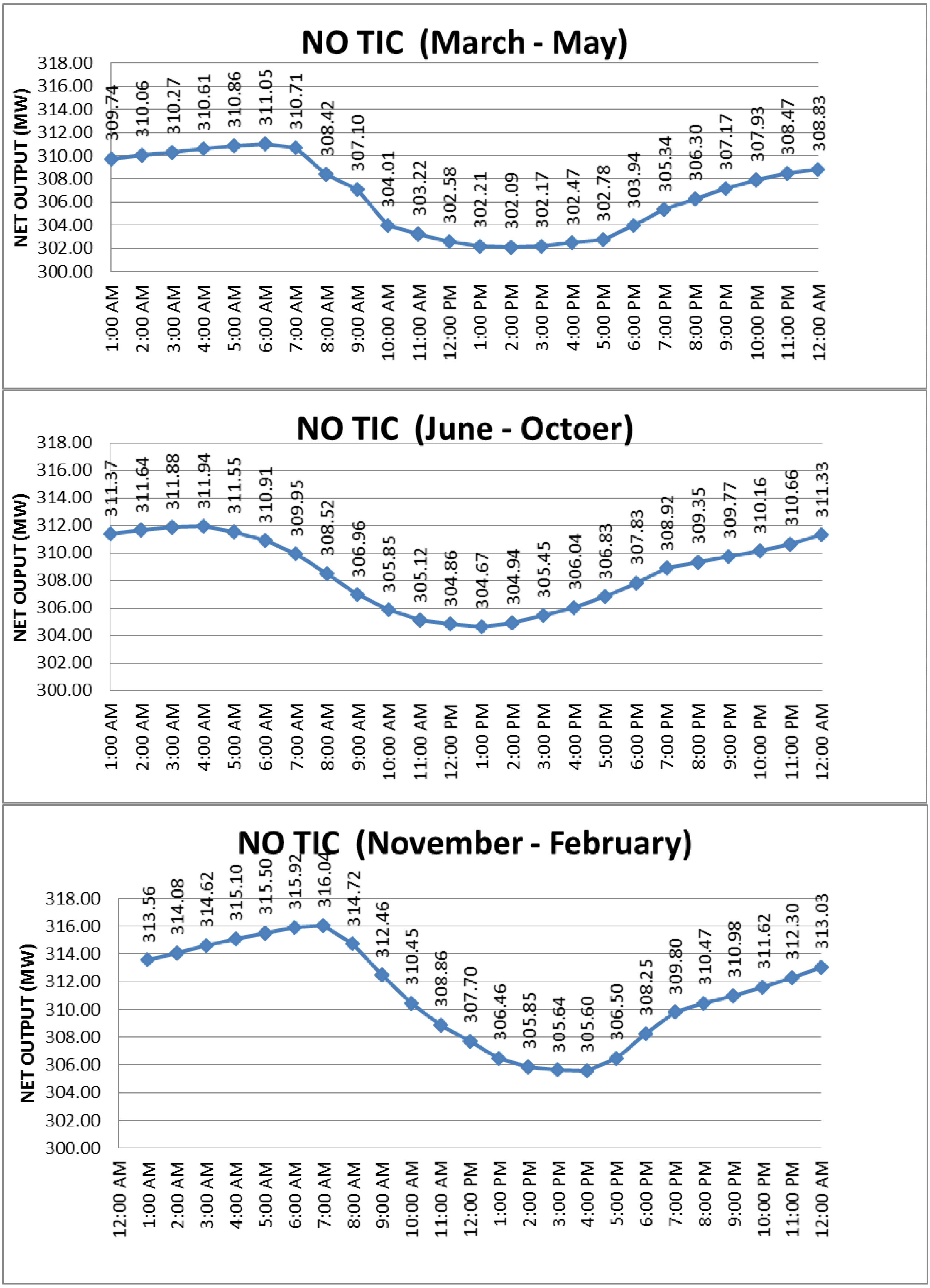


Figure 4.3 Net output of the existing plant case

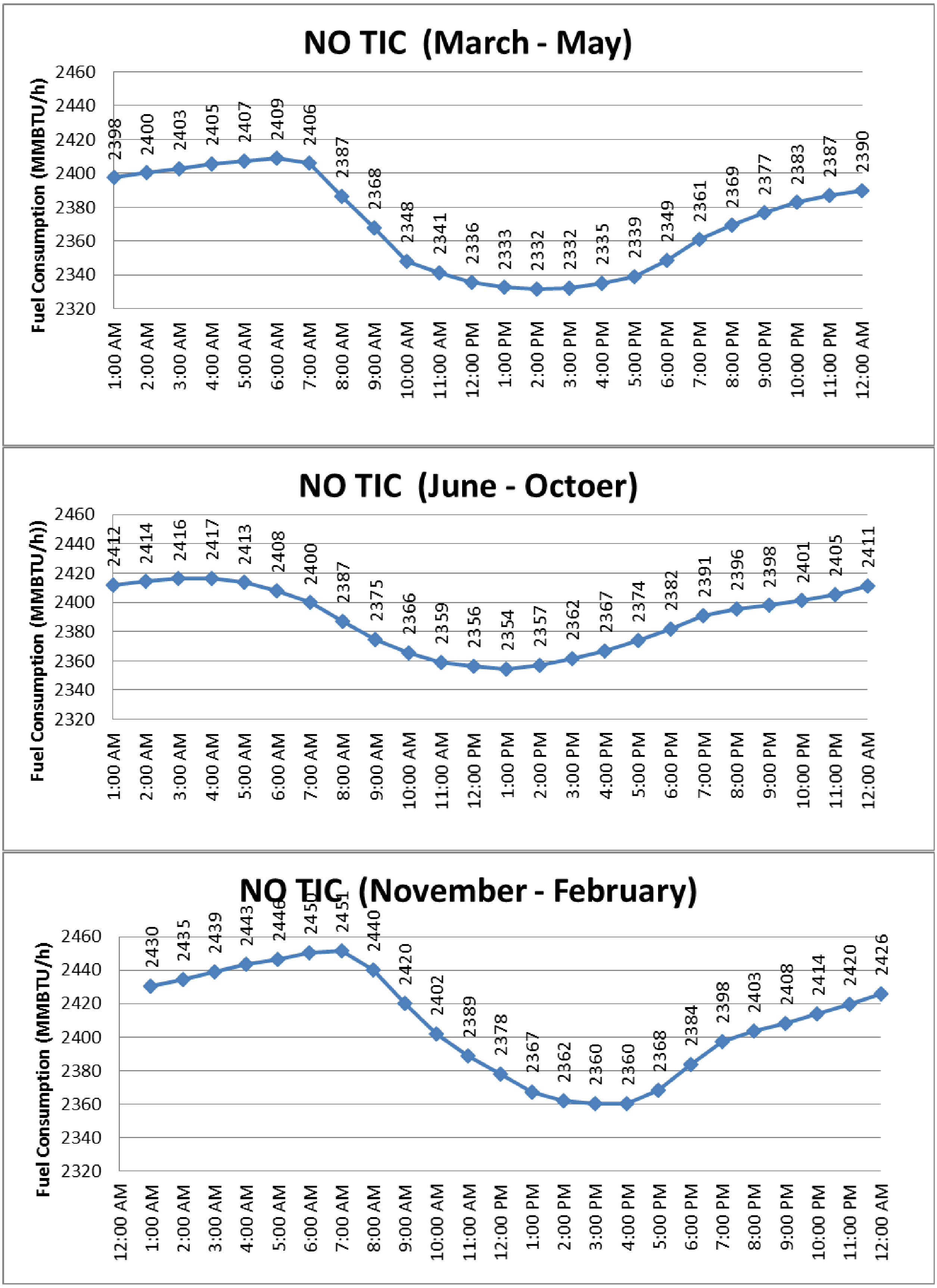


Figure 4.4 Fuel consumption of the existing plant case

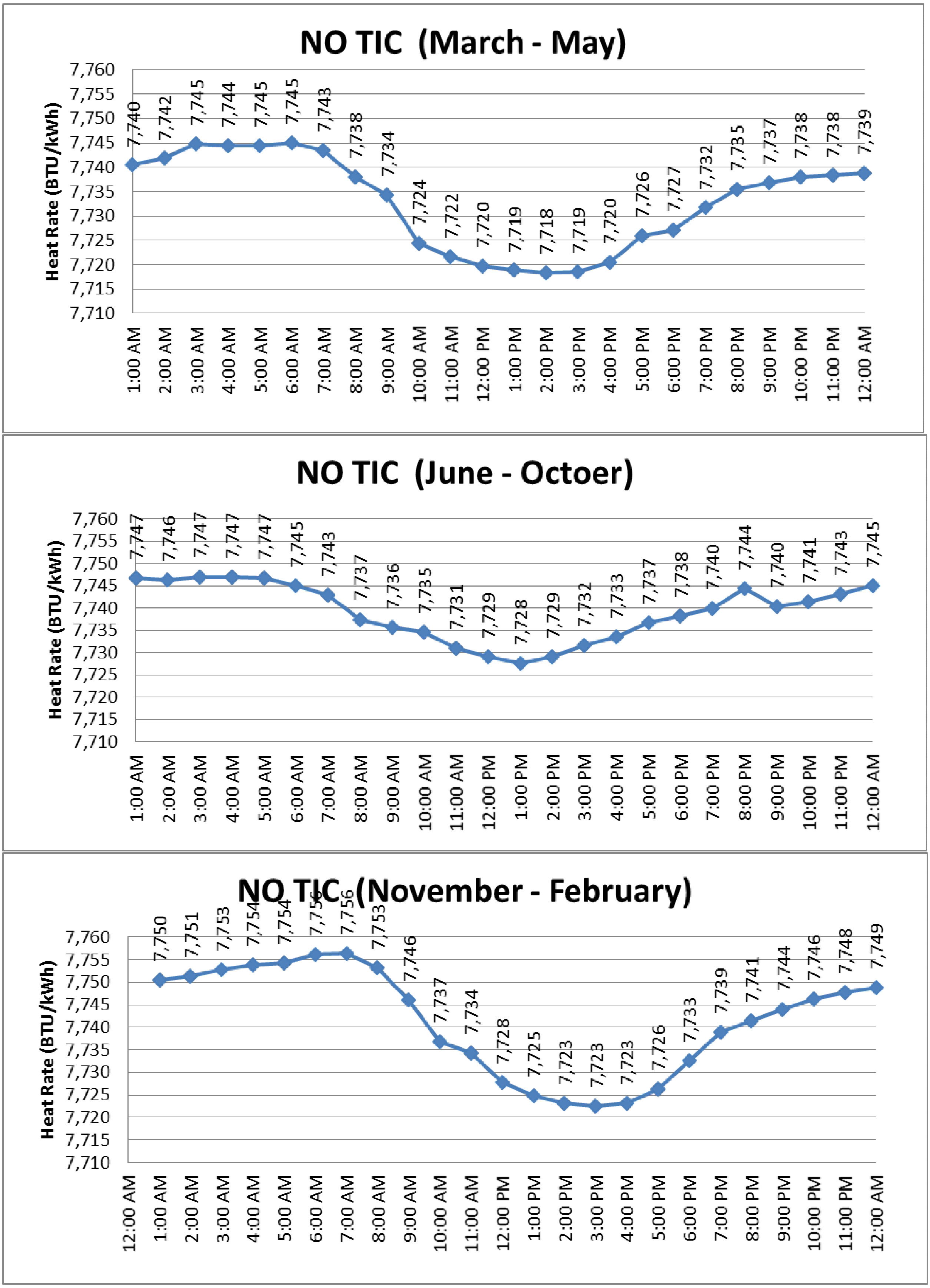
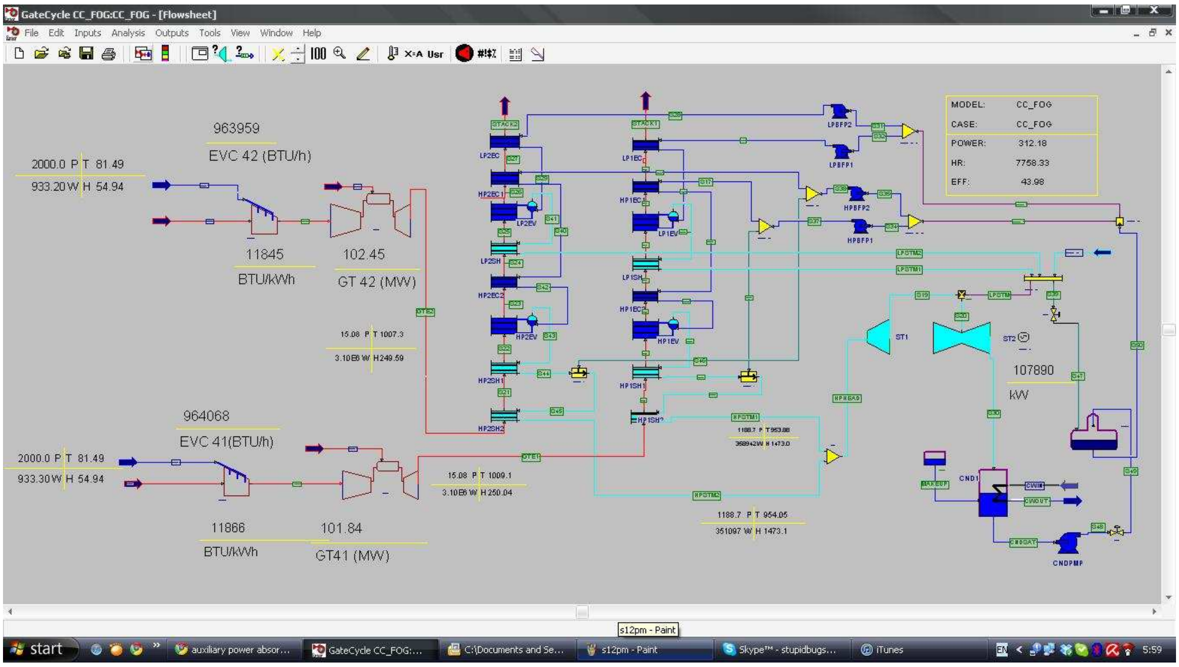


Figure 4.5 Heat rate of the existing plant case

Case 2: Evaporative Cooling System (Fogging System)

Simulation model of evaporative system case study was developed by adding the evaporative cooler in an existing plant as illustrated in Figure 4.6. A high-pressure fogging system was selected for study in an evaporative cooling system case. The assumption of design criteria of the evaporative cooling system is as follows:

- Fogging Pressure = 13.8 MPa
- Relative Humidity exiting from high pressure fogging system = 90%
- Parasitic load of high pressure fogging system = 0.08 kW/TR [10]



MODEL: CC_FOG
CASE: CC_FOG
POWER: 312.18
HR: 7758.33
EFF: 43.98

Figure 4.6 Bangpakong Combined Cycle Power Plant Block 4 model with evaporative cooling system

Table 4.5 Input variable parameters in simulation model with evaporative cooling systems

Description	Used data
GT ambient air temperature	As indicated Table A in Appendix A
GT relative humidity	As indicated Table B in Appendix A
Condenser cooling water temperature	Assume equal ambient air temperature
Evaporative cooling water temperature of each GT	Assume equal ambient air temperature

Table 4.5 shows the input variable parameters used to generate the variable performance output, which are gas turbine power performance (power output, efficiency and heat rate), compressor inlet temperature, water consumption, energy transferring from water, steam turbine performance and overall performance. The results of the evaporative cooling case study are represented in profiles that compare power output, power output improvement, fuel consumption variation and percentage of heat rate changing as shown in Figures 4.8, 4.9 and 4.10 respectively. The details are shown in Appendix C.

As shown in Figure 4.7, the evaporative cooling system effectively enhances the power output in winter because of the limitations of the evaporative cooling system in which saturation is reached so evaporative cooling system is unable to evaporate more water into the air stream, similarly low humidity can provide efficient power augmentation. This option has maximum and average generation power output augmentation of 6.77 MW and 3.05 MW, fuel consumption variation of 91.632 GJ/h and 40.735 GJ/h, heat rate changing of 1.45% and 0.62%. Annual power output enhances 0.94 % from 2,201,572 MWh to 2,222,351 MWh.

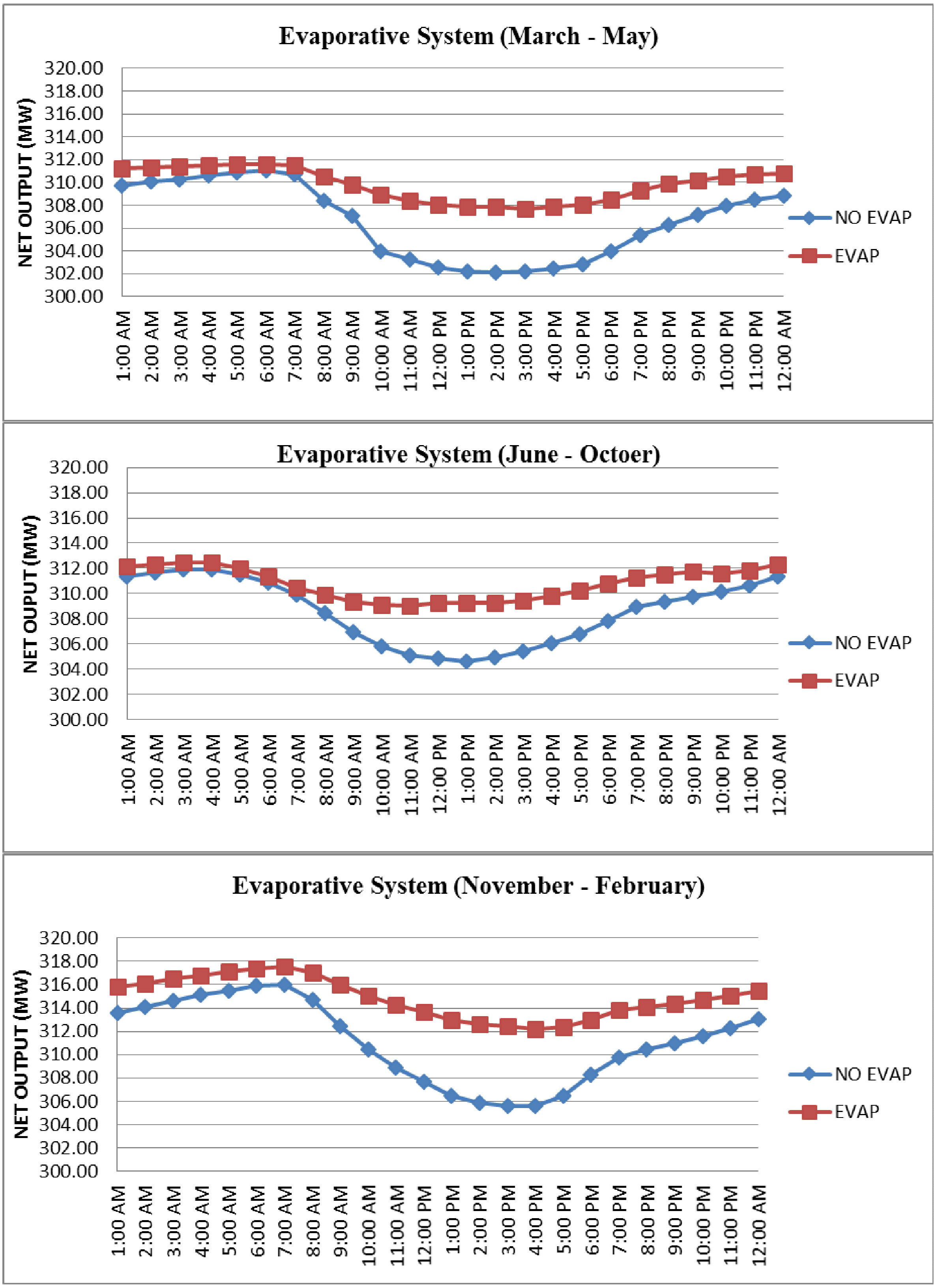


Figure 4.7 Net output of evaporative cooling system case

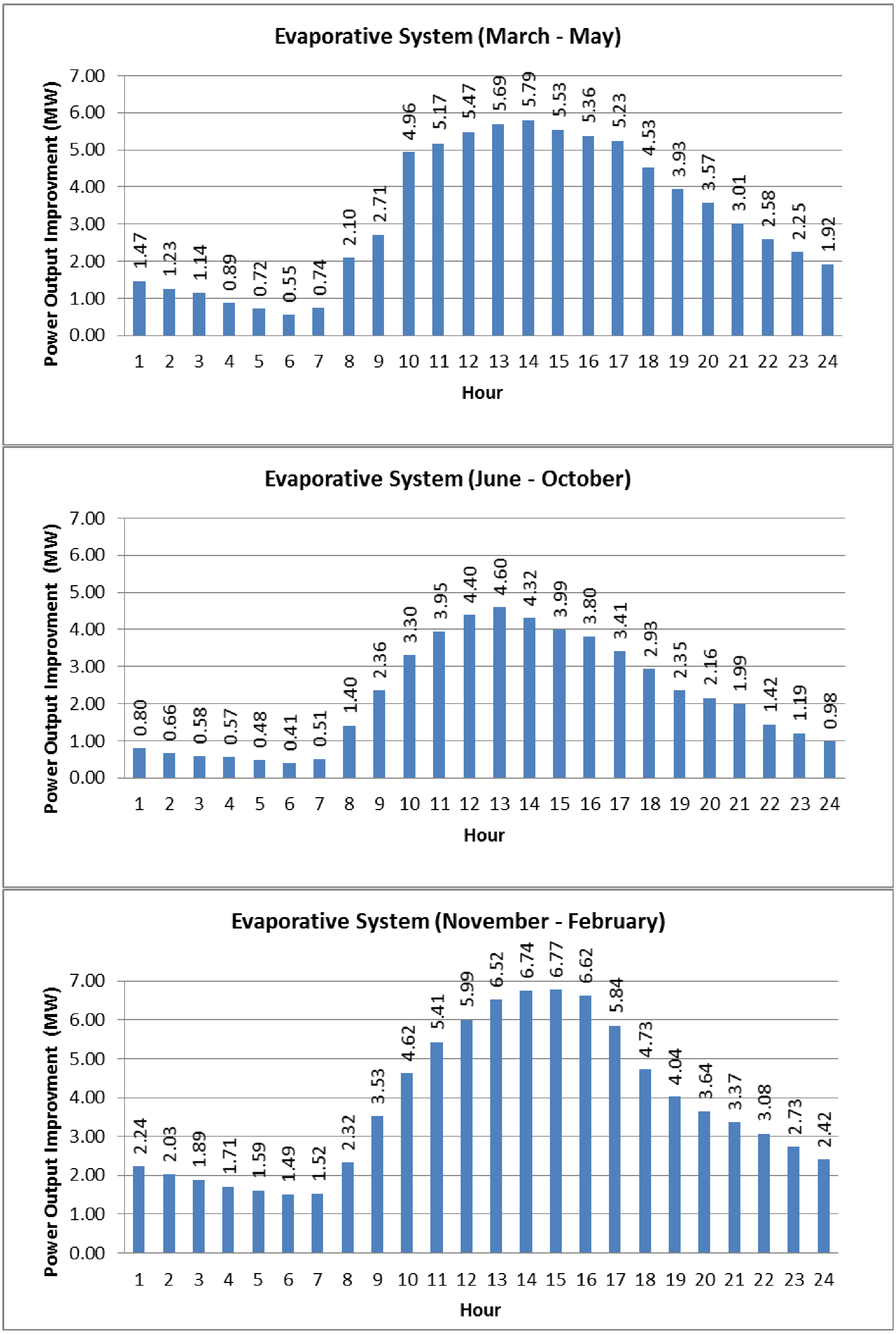


Figure 4.8 Increased output power of evaporative cooling system case

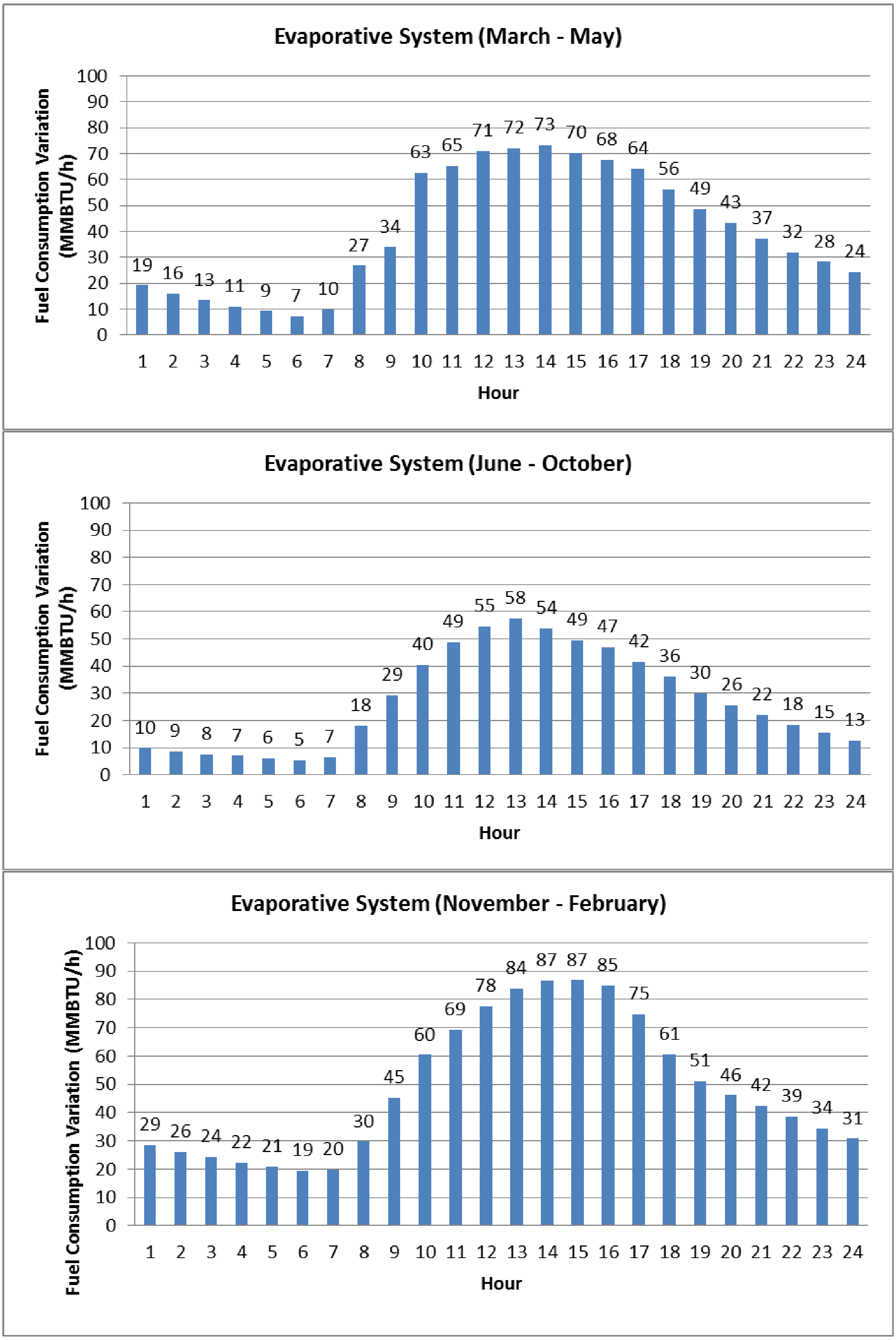


Figure 4.9 Fuel consumption variation of evaporative cooling system case

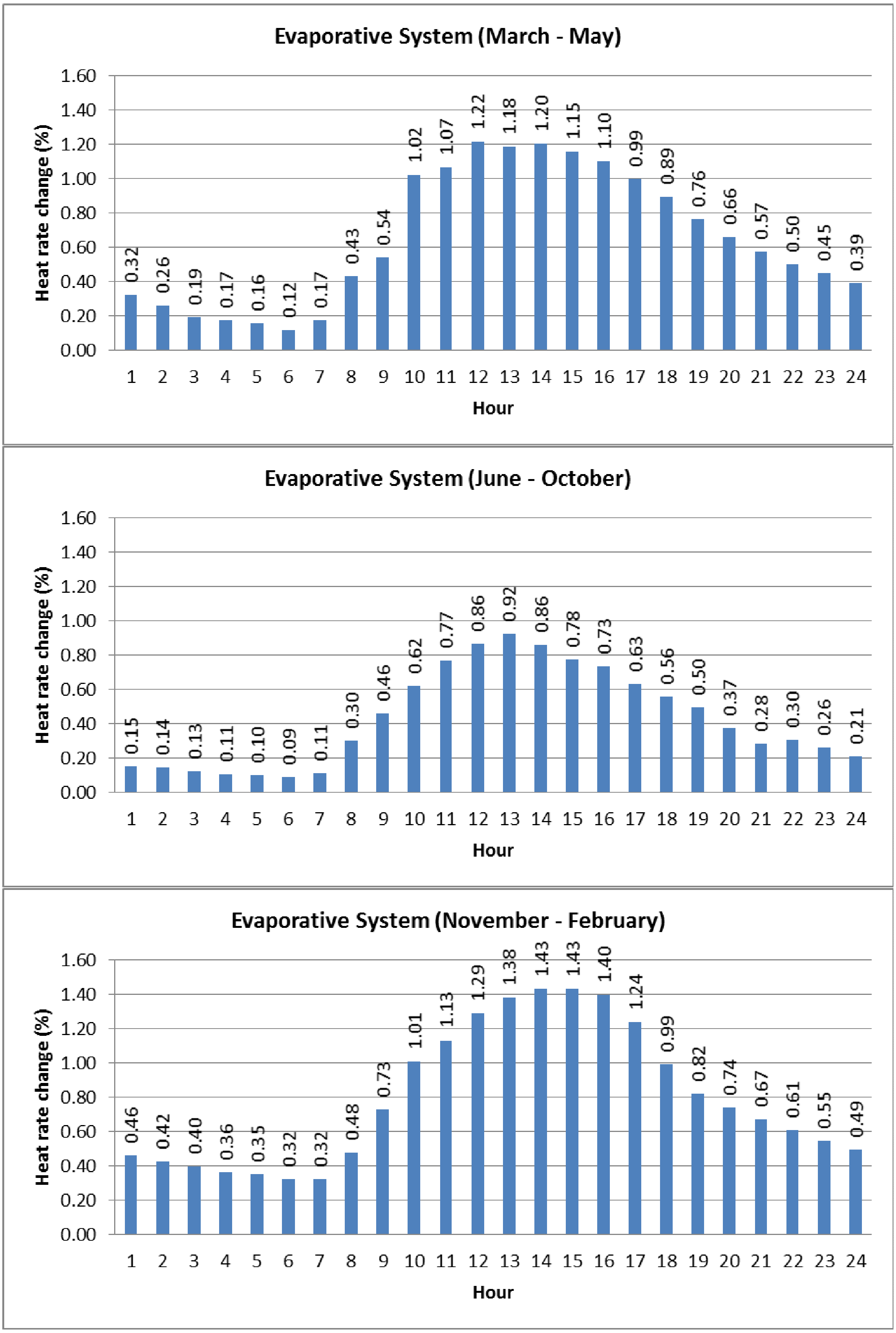
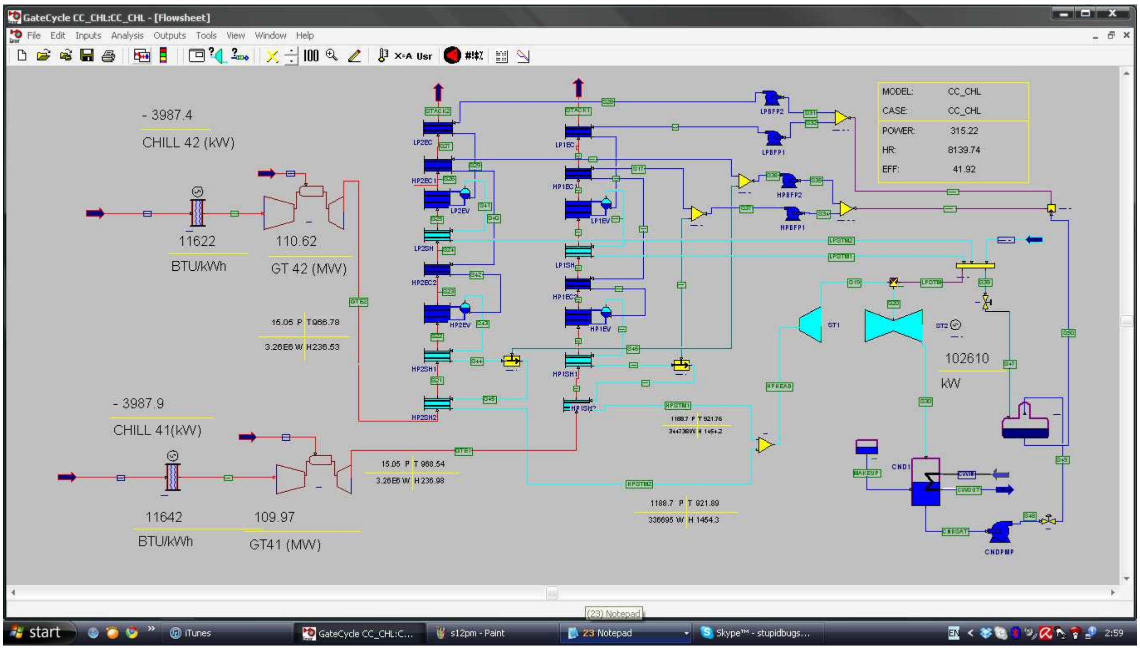


Figure 4.10 Percentage of heat rate change of evaporative cooling system case

Case 3: Mechanical Chiller System

Simulation model of the mechanical chiller system case study was developed by adding the electrical chiller system in existing plant, as shown in Figure 4.11. The mechanical chiller with cooled water was used to study in this case. Assumption of design criteria of mechanical chiller system is as follows:

- Design temperature of compressor inlet = 15 ^{o}C
- Relative Humidity exiting = 100 %
- Parasitic load of mechanical chiller system = 1 kW/TR



MODEL: CC_CHL
CASE: CC_CHL
POWER: 315.22
HR: 8139.74
EFF: 41.92

Figure 4.11 Bangpakong Combined Cycle Power Plant Block 4 Model with mechanical chiller system

Table 4.6 Input variable parameters in simulation model with mechanical chiller system

Description	Used data
GT ambient air temperature	As indicated in Table A in Appendix A
GT relative humidity	As indicated in Table B in Appendix A
Condenser cooling water temperature	Assume equal ambient air temperature

Table 4.6 shows the input variable parameters that were used to generate the variable outputs, including gas turbine power performance (power output, efficiency and heat rate), energy of chilling, steam turbine performance and overall performance. The results of mechanical chiller case study are represented, which is comparison of output power, power output improvement, fuel consumption variation and percentage of heat rate changing, as shown in Figures 4.13, 4.14 and 4.15 respectively. The detailed results are shown in Appendix C.

As shown in Figure 4.12, the mechanical chiller system generates the stable power output at design compressor inlet temperature. The small variable power outputs originate from variable parasitic loads caused by the mechanical chiller. This option has maximum and average generation power output augmentation of 9.74 MW and 6.09 MW, fuel consumption variation of 334.811GJ/h and 199.184 GJ/h, heat rate changing of 6.85 and 5.33. Annual power output enhances 1.93% from 2,201,572 MWh to 2,244,018 MWh.

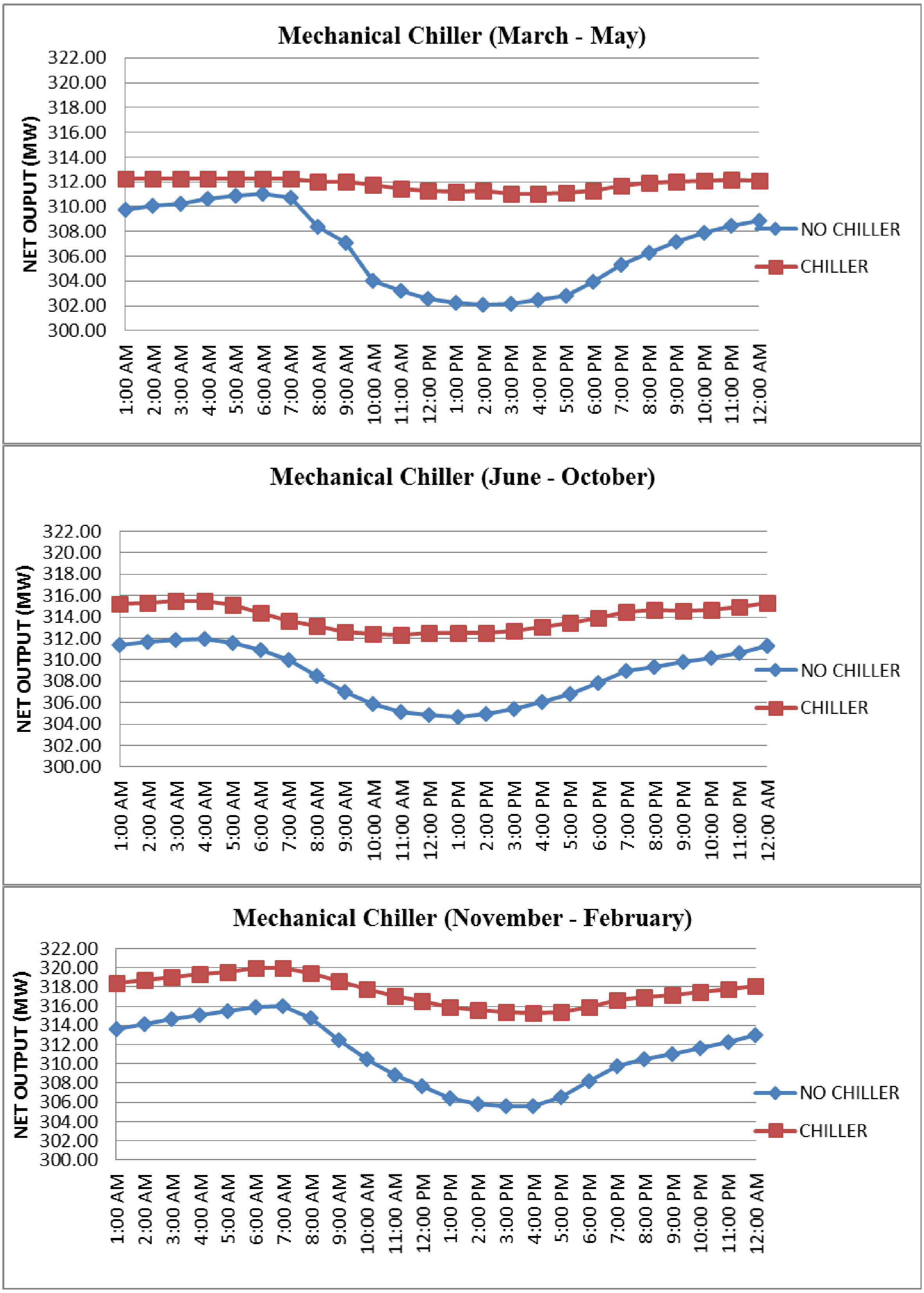


Figure 4.12 Net output of mechanical chiller system case

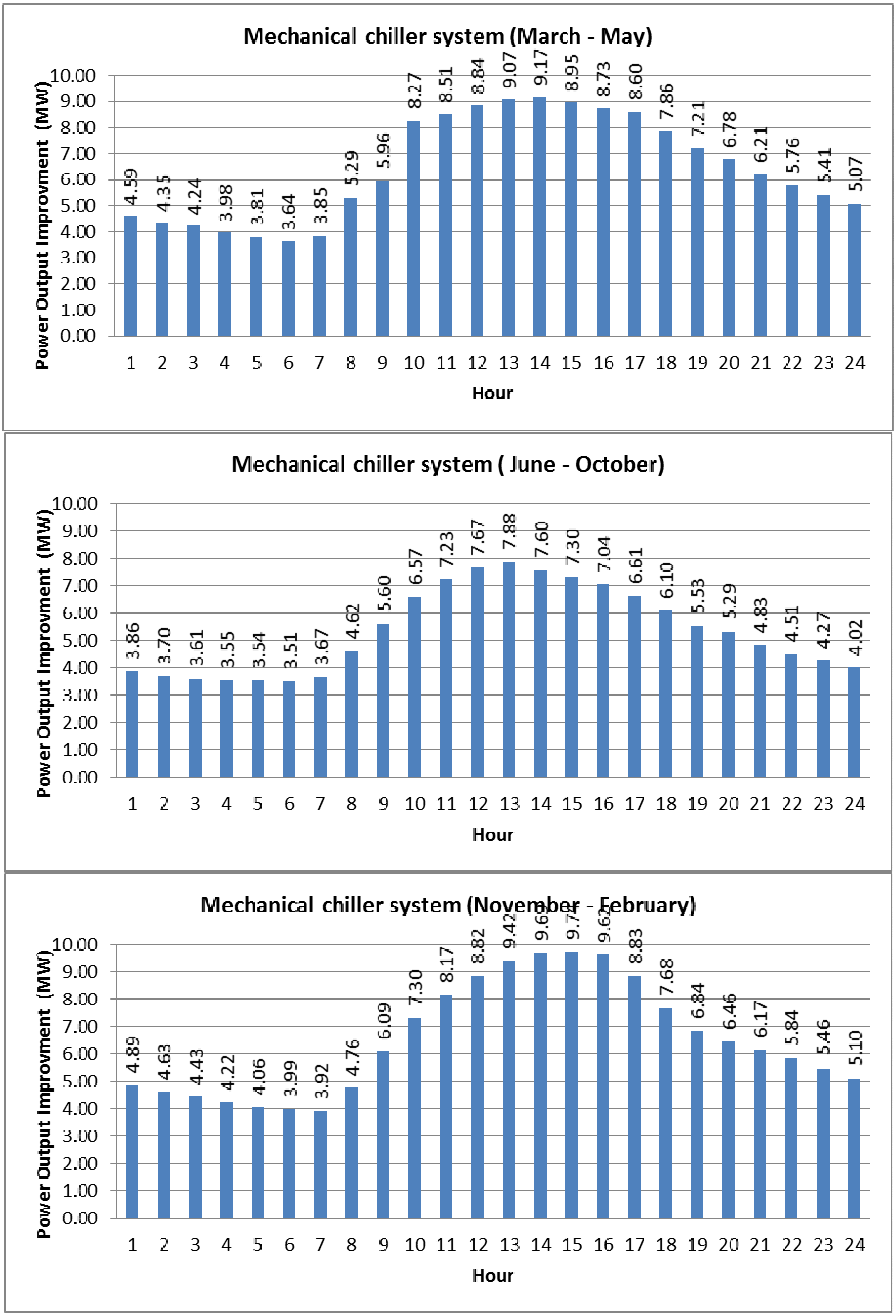


Figure 4.13 Increased output power of mechanical chiller system case

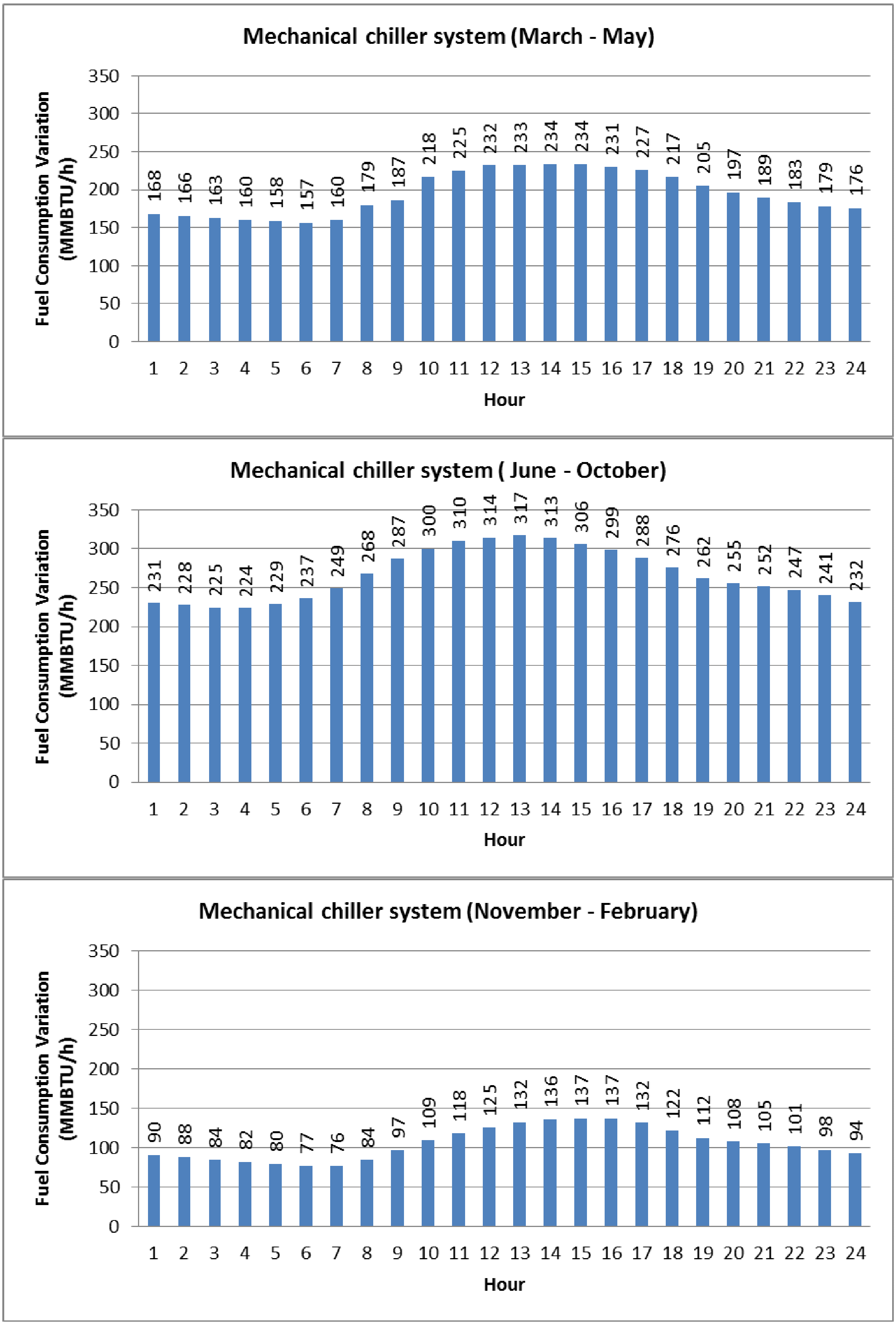


Figure 4.14 Fuel consumption variation of mechanical chiller system case

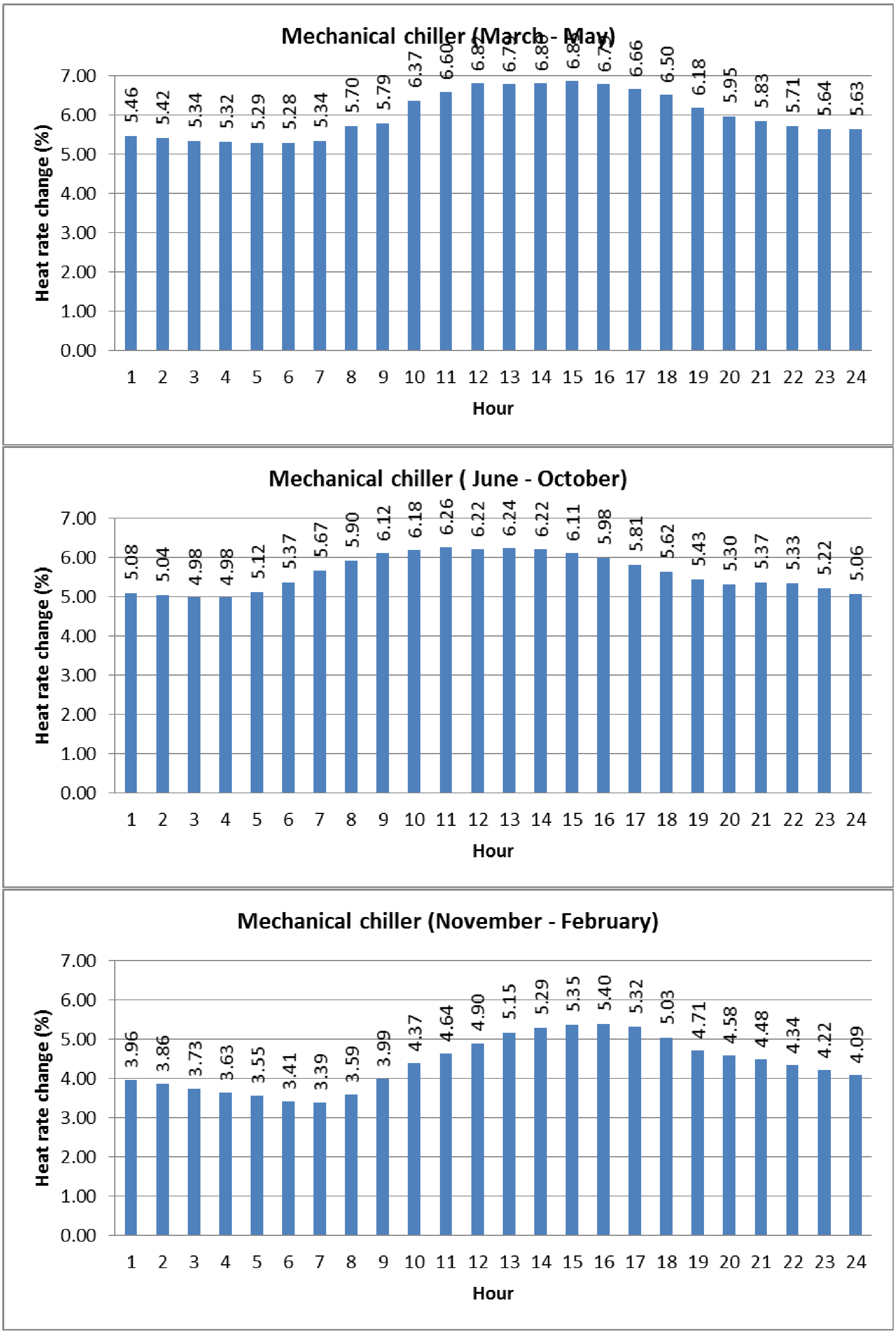
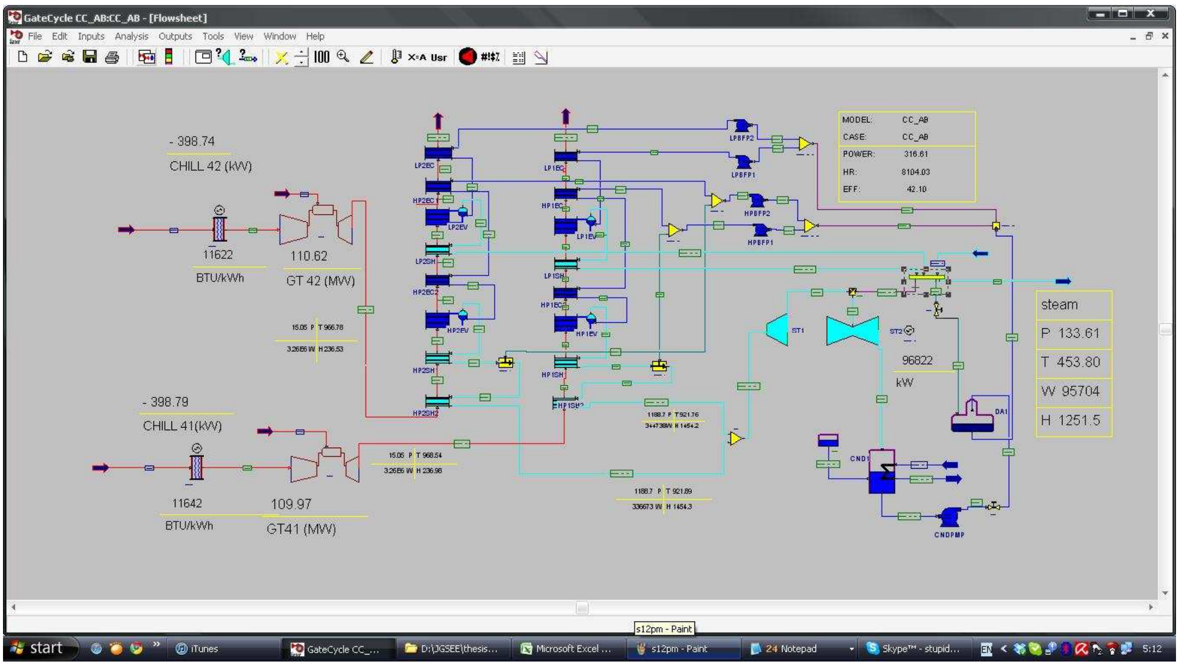


Figure 4.15 Percentage of heat rate change of mechanical chiller system case

Case 4: Absorption Chiller System

Simulation model of absorption chiller system case study was developed by adding the electrical chiller system in existing plant and extracted steam at low pressure as shown in Figure 4.16. The mechanical chiller with cooled water was used to study this case. The design criteria of the evaporative cooling systems are as follows:

- Design temperature of compressor inlet = 15 ^{o}C
- Relative Humidity exiting = 100 %
- Assume parasitic load of mechanical chiller system = 0.1 kW/TR
- Assume steam consumption = 1.5 x 10^{-3} kg/s/TR [10]



MODEL:	CC_AB
CASE:	CC_AB
POWER:	316.61
HR:	8104.03
EFF:	42.10

Figure 4.16 Bangpakong Combined Cycle Power Plant Block 4 Model with absorption chiller system

Table 4.7 Input variable parameters in simulation model with absorption chiller system

Description	Used data
GT Ambient air temperature	As indicated in Table A in Appendix A
GT Relative humidity	As indicated in Table B in Appendix A
Condenser cooling water temperature	Assume equal ambient air temperature
Steam consumption to absorption chiller	Assume 12 lbm/h/TR [10]

Table 4.7 shows the input variable parameters that were used to generate the variable output, including gas turbine power performance (power output, efficiency and heat rate), compressor inlet temperature, energy transfer from water, steam turbine performance and overall performance. The results of absorption chiller case study are represented by comparison of output power, increased output power and percentage of heat rate change as shown in Figures 4.18, 4.19 and 4.20 respectively. The detailed results are shown in Appendix C.

As shown Figure 4.17, the absorption chiller system generates the stable power output at design compressor inlet temperature similar to the mechanical chiller system. The variable power outputs originated from the variable parasitic loads (electrical power) by the absorption chiller and lower steam turbine power output (from steam energy extraction). This option has maximum and average generation power output augmentation of 11.58 MW and 7.67 MW, fuel consumption variation of 268.248 GJ/h and 186.471 GJ/h, heat rate changing of 6.00 % and 4.8 %. Annual power output enhances 2.44% from 2,201,572 MWh to 2,255,267 MWh.

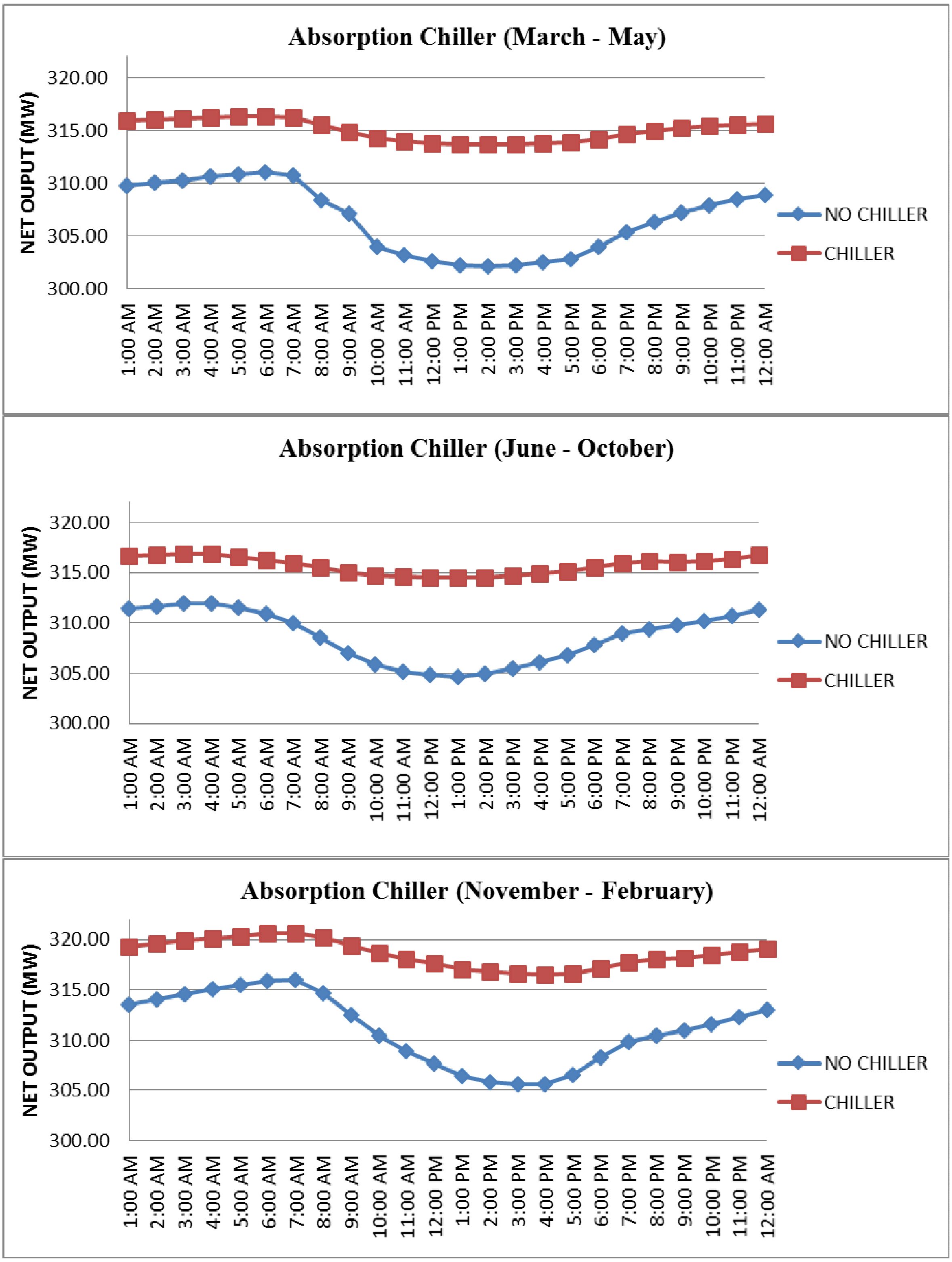


Figure 4.17 Net output of absorption chiller system case

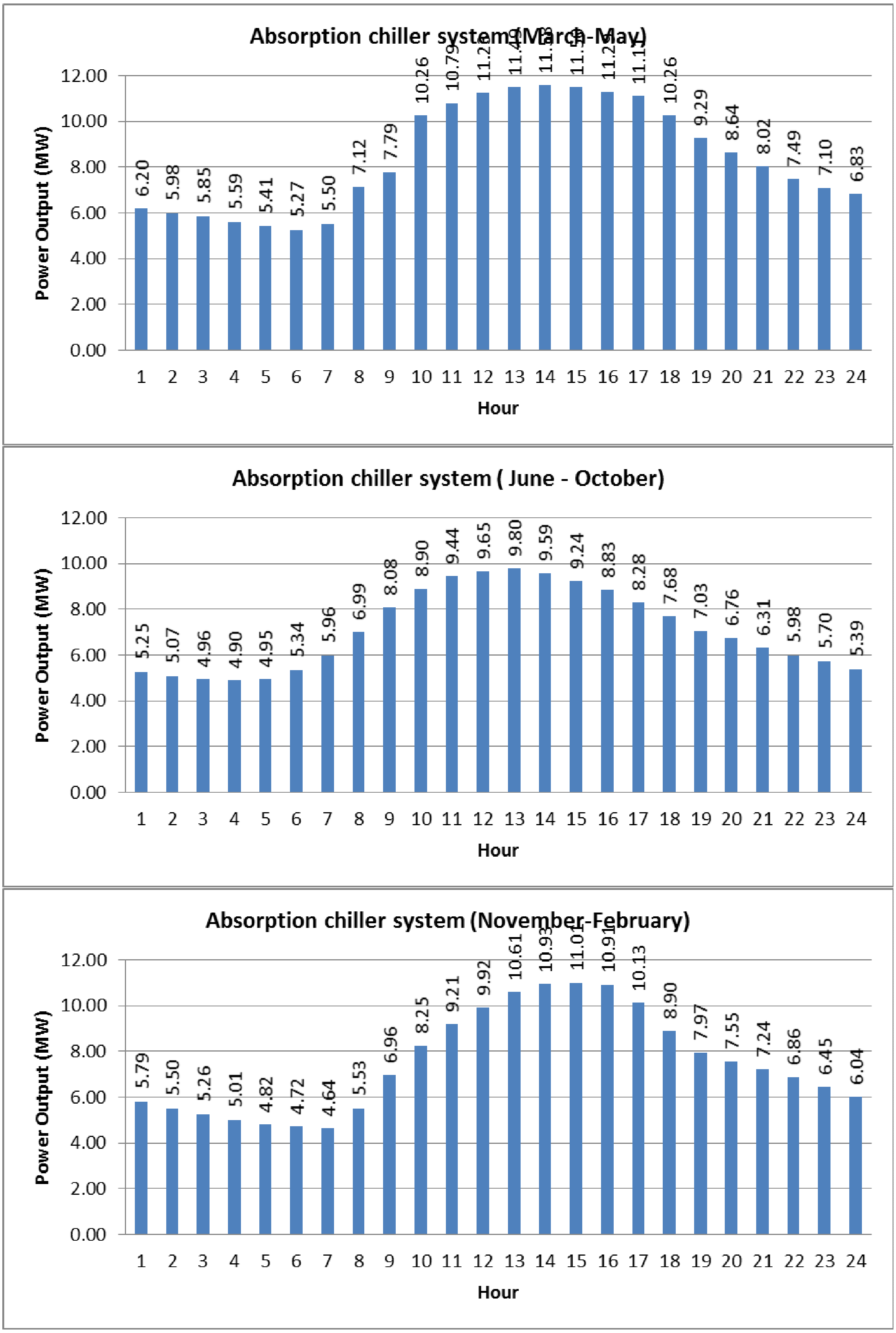


Figure 4.18 Increased output power of absorption chiller system case

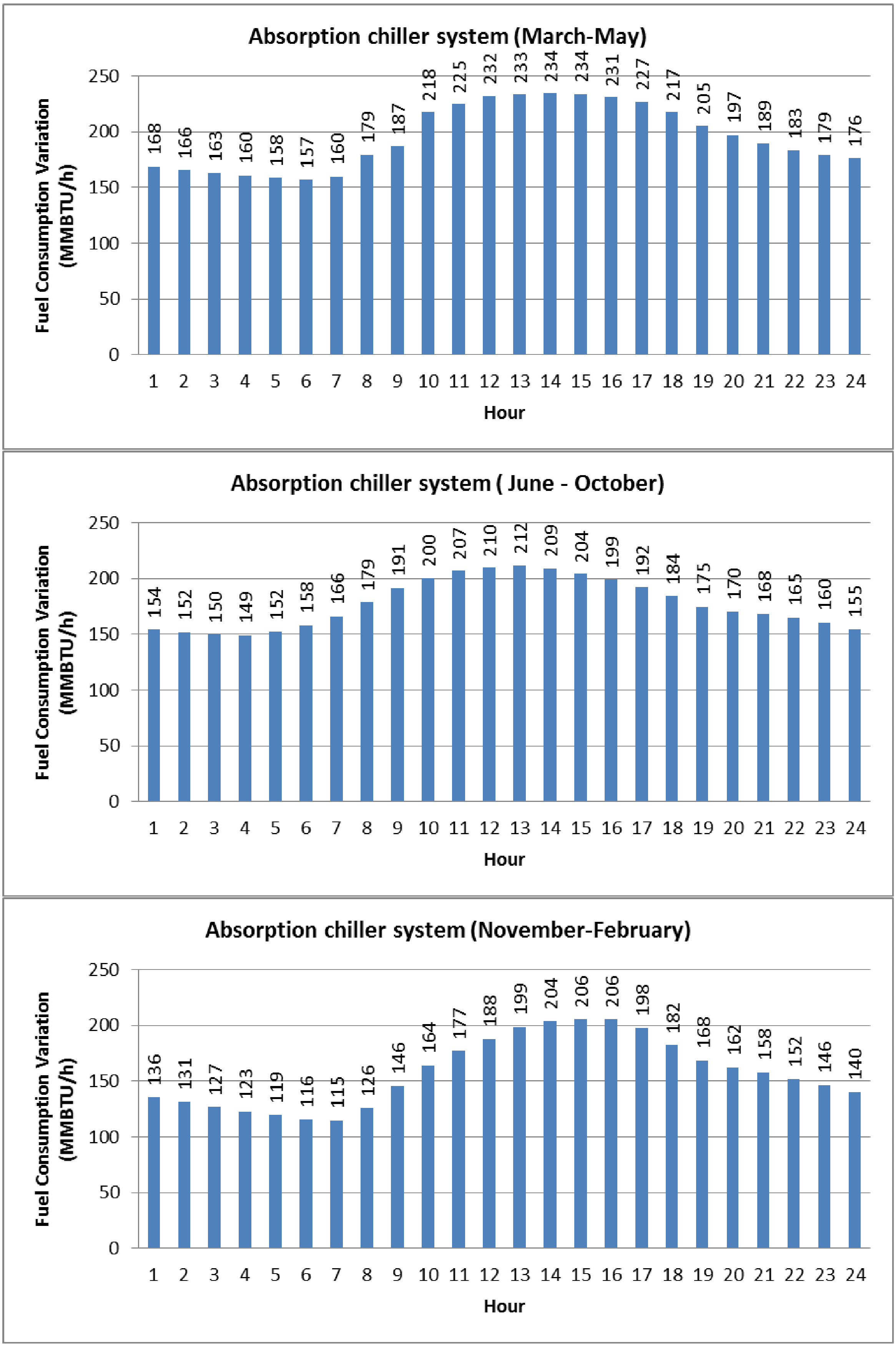


Figure 4.19 Fuel consumption variation of absorption chiller system case

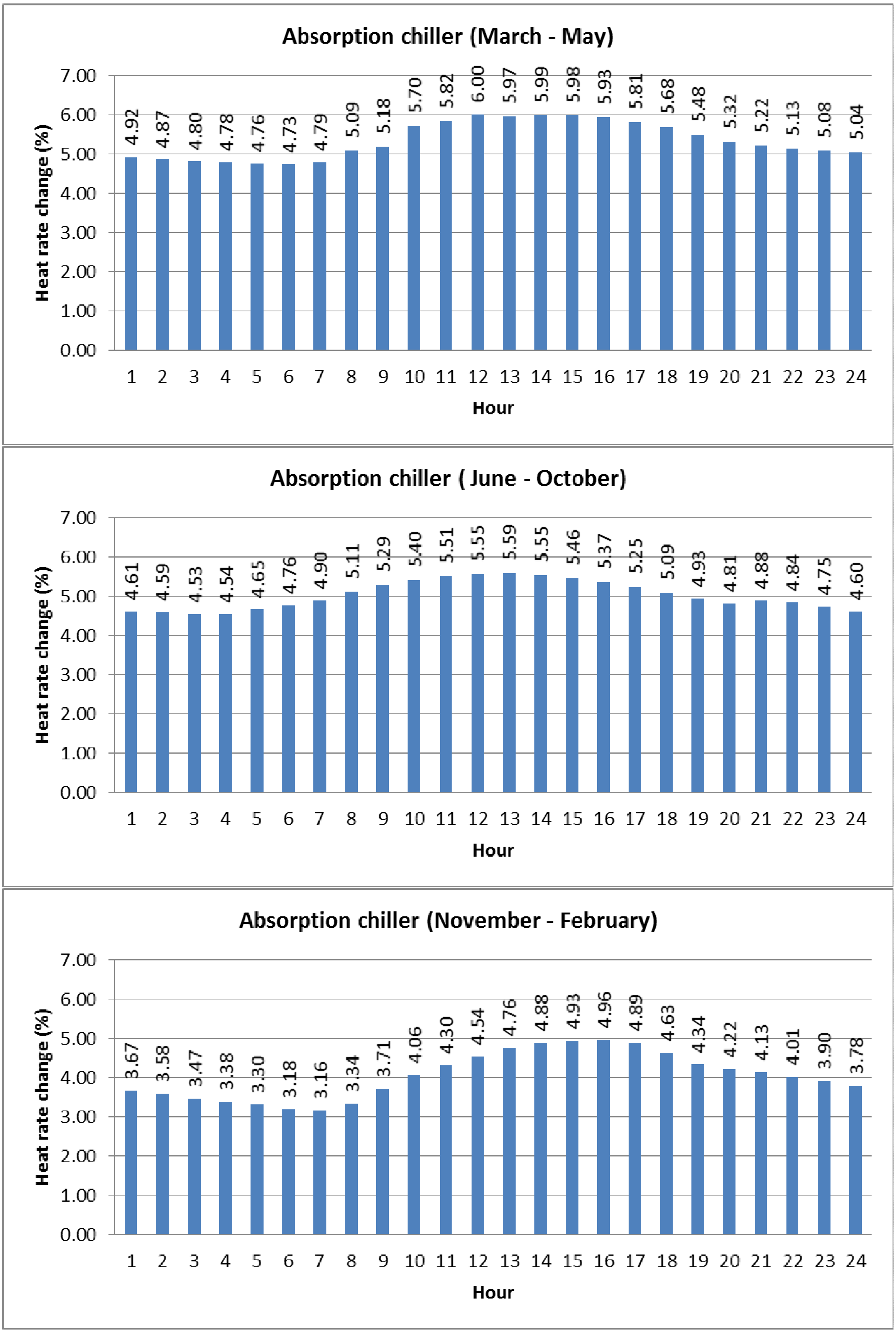


Figure 4.20 Percentage of heat rate change of absorption chiller system case

4.2.2 Gas Turbine Inlet Cooling System Comparison and Analysis

The results of all alternatives correspond to gas turbine behavior in which the compressor inlet air temperature affects on power augmentation. Figure 4.21 presents mass flow variation (generate from simulation model by temperature variation) effect on power output of BPK gas turbine. Inlet air temperature affects the density and/or mass flow of the air intake to the compressor, inlet air cooling increases output by taking advantage of the gas turbine's characteristic of higher mass flow rate and, thus, output as the compressor inlet temperature decreases, and then it changed gas turbine performance.

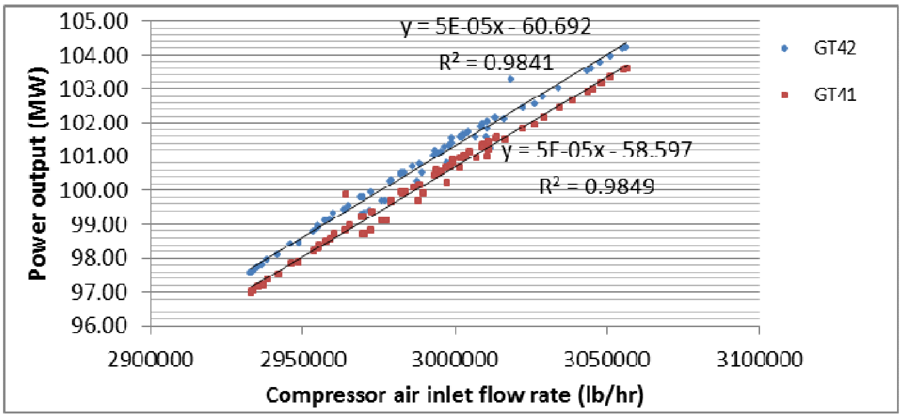
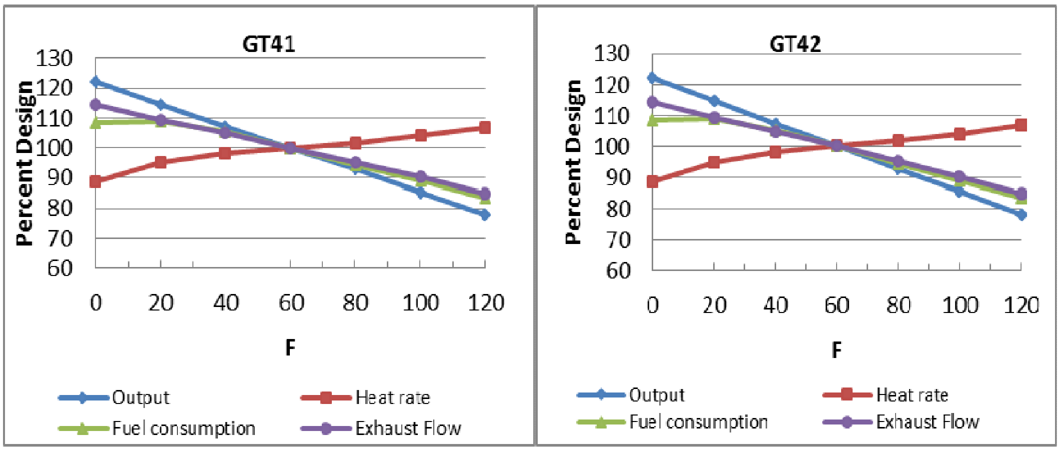


Figure 4.21 Variation power output by inlet mass flow

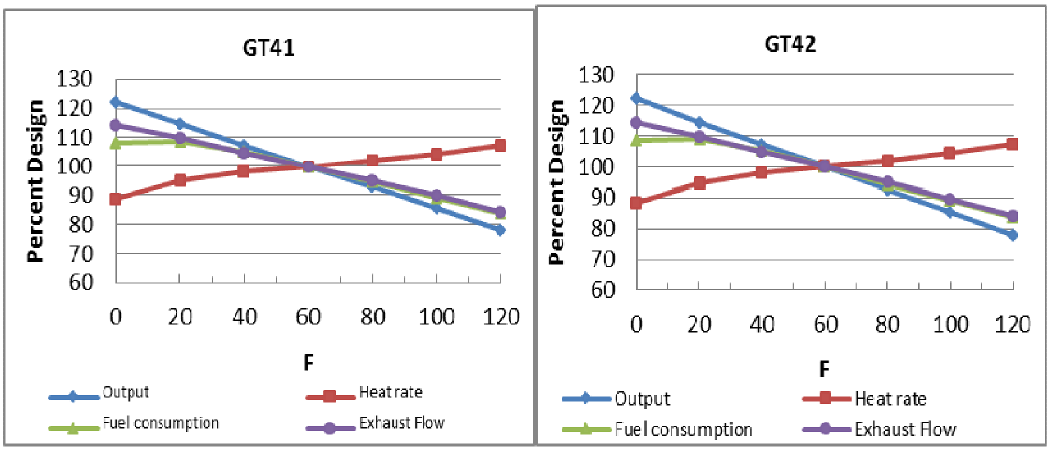
Figure 4.22 shows how temperature and humidity variation are produced as a result of output, fuel consumption, heat rate and exhaust flow rate without consideration of the parasitic load of the cooling system. It presents cooling system, lower temperature and higher humidity, heat rate gain to gas turbine plant from humidity less than the heat rate gain due to temperature. As gas turbine, the cooling system, temperature reduction enhances power output whereas it increases fuel consumption and heat rate because of balancing of mass flow in combustion and its parasitic load.

Table 4.8 provides the comparison of alternative options, which are the evaporative system, the mechanical chiller system and the absorption chiller system. The greatest power augmentation is generated by absorption chiller system which produces maximum net power augmentation of 11.58 MW, the highest average power improvement is 7.67 MW or 2.49 % of existing power. GT 41 and GT42 have average enhancing power output of 9.45 MW (+9.44%, 100.14 MW to 109.59) and 9.52 MW (+9.45 %, 100.72 MW to 110.24 MW) respectively, total gas turbine power augmentation is 18.97 MW while average steam turbine power output become lower from 107.90 MW to 96.59 MW (11.31

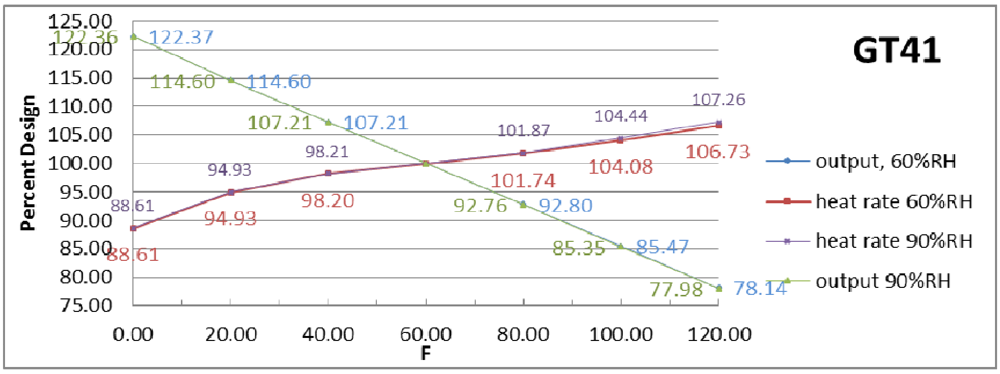
MW or –10.48%). The absorption chiller system has enhanced annual power output of 2.44%. The reduction effect of the steam turbine output is due to lower temperature of foul gas and lower steam energy (extract steam to absorption chiller).



(a) Constant 60%RH



(b) Constant 90%RH



(c) Comparison

Figure 4.22 Effect of ambient temperature and humidity for BPK gas turbine

Mass flow rate of the compressor inlet increases and the exhaust flow rate becomes higher when compressor inlet temperature is lower. Although cooling systems have an affect on higher exhaust flow rate in which it increases performance of heat recovery, it causes lower exhaust temperature in which heat recovery gets less performance. Parasitic load of adding mechanical chiller system is higher than adding absorption chiller even steam energy is extracted by absorption chiller. Evaporative cooling system produces fuel consumption value and heat rate value greater than mechanical chiller and absorption chiller because it has lower parasitic load and, thus balancing of fuel consumption and compressed air flow rate for complete combustion in combustion chamber, air passes through evaporative system consume fuel less than air leaves behind chiller system. However, selection of the best alternative cannot be completed taking finance into consideration.

Table 4.8 Comparison of alternative options

		Existing Plant Case	**Evaporative System Case**	**Mechanical Chiller Case**	**Absorption Chiller Case**
Power Output (Avg.) , MW	GT41	100.14	102.15	106.17	109.59
	GT42	100.72	102.76	106.82	110.24
	ST40	107.90	106.91	101.85	96.59
	CC	308.76	311.82	314.84	316.42
Power Output Improvement, MW	Max.	-	6.77	9.74	11.58
	Avg.	-	3.05	6.09	7.67
	%	-	0.99	1.98	2.49
Power Output, MWh/yr		2,201,572	2,222,351 (0.94%)	2,244,018 (1.93%)	2,255,267 (2.44%)
Fuel Consumption Variation, GJ/h	Max.	-	91.632	268.248	268.248
	Avg.	-	40.735	186.471	186.471
	%	-	1.62	7.42	7.42
Fuel Consumption, 10^{13} kJ/yr		1.797	1.825	1.929	1.929
Heat Rate Change (%)	Max.	-	1.45	6.85	6.00
	Avg.	-	0.62	5.33	4.80

However finance is also the key point to an acceptable decision with investment and funds. There are many variables involved in the financial consideration, and many individuals and departments participate in the process. Table 4.9 and Figure 4.23 present the cost effectiveness comparison of inlet cooling system. The absorption chiller system generated greatest annual augmented power output while its investment cost was high. By cost effectiveness ratio, the evaporative cooling system provide the greatest of cost effectiveness of 7.18 $/MWh. It therefore supported the evaporative system is the best alternative option for performance improvement for BPK combined cycle power plan. The evaporative cooling system also provided the greatest net present value of US$730,000 which was positive value on given weighted average cost of capital raised for additional fund of 9.1 %. The feasibility is detailed in Appendix E.

Table 4.9 Cost effectiveness comparison

	Evaporative Cooling	Mechanical Chiller	Absorption Chiller
Total Cooling Load (TR)	1,420	9,400	9,400
Investment Cost ($)	149,105	16,303,226	18,129,032
Annual augmented MWh	20,779	42,447	53,695
Investment Cost /Augmented annual output ($/MWh)	7.18	384.09	337.63

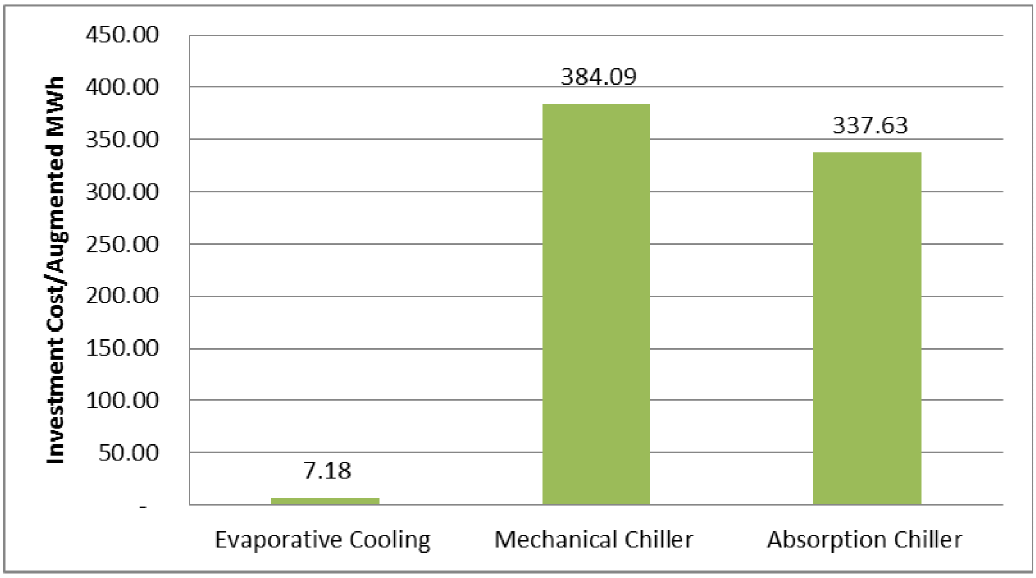


Figure 4.23 Increment cost per augmented annual power output

Sensitivity analysis shows to what extent the viability of a project is influenced by variations in major quantifiable variables [14]. It focuses on analyzing the effects of changes in variables of theweighted average cost of capital raised for additional funds and plant factor on the project's NPV.

Table 4.10 NPV and Sensitivity

Item		Variables	NPV	SI	SV
Fogging system	Base case		730,001		
	WACC	10.1%	697,207	-0.41	N/A
	WACC	8.1%	764,808		
	Plant factor	90%	1,010,174	1.34	74
	Plant factor	50%	449,828		
Mechanical chiller system	Base case		-22,944,726		
	WACC	10.1%	-22,827,403	-0.05	N/A
	WACC	8.1%	-23,062,550		
	Plant factor	90%	-25,498,048	0.39	257
	Plant factor	50%	-20,391,476		
Absorption chiller system	Base case		-21,220,060		
	WACC	10.1%	-21,245,920	0.01	N/A
	WACC	8.1%	-21,185,279		
	Plant factor	90%	-23,003,093	0.29	340
	Plant factor	50%	-19,437,028		

Note: At base case WACC is 9.1% and plant factor is 70%

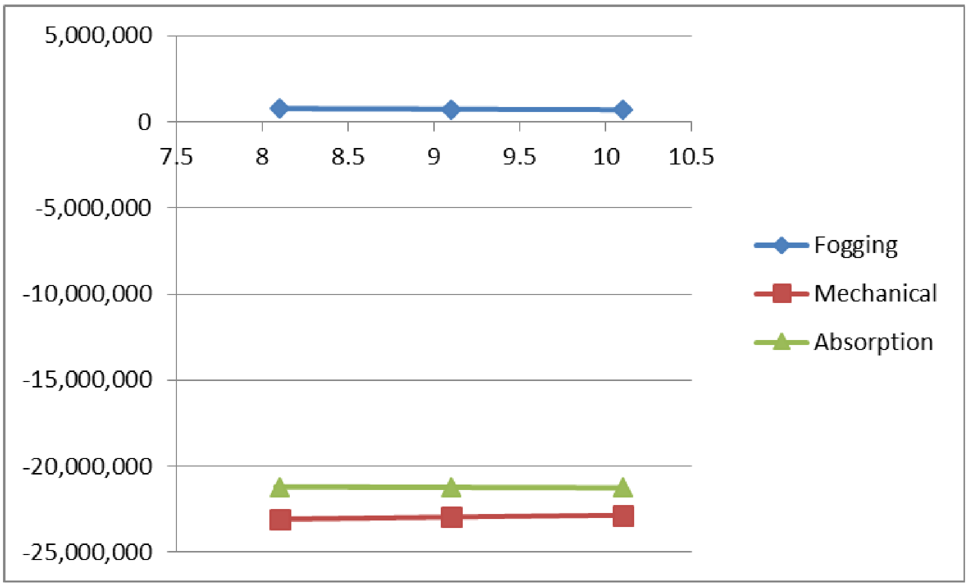


Figure 4.24 NPV variables on WACC variables

4.3 Primary Energy Saving (PES)

This part presents the determination of energy utilization and finance for alternative system. Primary Energy Saving or PES, calculated by using a simulation model result, was used to described the energy utilization.

According to the EU Directive, in the case of the overall efficiency of the CHP plant (η) in a reporting period has achieves the value in Annex II (a) of the CHP-Directive ($\eta > \eta_{CHP}$), the CHP plant does not generate non-CHP electrical energy ($p_{non\text{-}CHP}$). The non-CHP electrical energy ($p_{non\text{-}CHP}$) and the referring fuel energy ($f_{non\text{-}CHP,p}$) only have to be determined if the overall efficiency of the CHP plant (η) in a reporting period does not achieve the value(s) in Annex II (a) of the CHP-Directive. In this case the CHP overall efficiency (η_{CHP}) according to Annex II of the CHP Directive is applied to determine the power-to-heat ratio. For clearness, the PES of absorption chiller case is selected to describe as Table 4.10, meaning, fuel energy of 100 % generate electricity of 40.37 % and heat energy of 4.29 % then cause the overall efficiency of 44.66% which is lower than reference efficiency of 75% (does not achieve the value(s) in Annex II (a) of the CHP-Directive). Therefore the non-CHP electrical energy ($p_{non\text{-}CHP}$) and the referring fuel energy ($f_{non\text{-}CHP,p}$) have to be determined and calculate from power to heat ratio (σ_{CHP}) and efficiency of non-combined electrical energy. This case, meaning, fuel energy of 100% is used actually in this plant but only 9.94% (f_{CHP}/f) is used in cogeneration which have efficiency 75%. (generate electricity of 3.18% and heat energy of 4.29%), another part of fuel energy of 90.06% is used to generate electricity of 37.19% at efficiency of 41.30%.

Table 4.11 Subdivision of CHP and non-CHP energies for absorption chiller case

	Total	CHP	non-CHP,q	non-CHP,p
η	44.66 %	75%	-	41.30%
p	40.37	3.18	-	37.19
q	4.29	4.29	-	-
f	100	9.94	-	90.06

Table 4.11 shows sequentially the energy for CHP determination and primary energy saving in a one-year period of an alternative system. The sample PES calculation is presented in Appendix D. Currently, the BPK operation demonstrates in quite low efficiency and for this reason the BPK merit order is in low level. We found that primary energy saving of BPK cannot achieve a reference primary energy saving value (10%) base on the Thailand’s standard reference efficiency (85% and 45% for separate production of heat and electricity respectively) which have been used presently for VSPP, the PES value of this existing plant reduce from -2.06 % to -2.64 % in evaporative cooling system case, -4.94 % in mechanical chiller case and -5.54 % in absorption chiller case. The result shows that PES cannot be improved by adding the inlet cooling systems, which are high pressure fogging system, mechanical system and absorption chiller system by extraction steam from low pressure steam turbine and these systems reduces the overall efficiency.

The Banpakong Combine Cycle Power Plant unit 4 was constructed more than 20 years ago. The commission decision of 21 December 2006 of European committees specified that efficiency reference values for the separate production of electricity should be related to the year of construction of a cogeneration unit. Moreover, correction factors which relate to the climatic situation should be applied to the reference values because the thermodynamics of generating electricity from fuel depend on the ambient temperature. Also the Annex III of Directive 2004/8/EC indicate that if the cogeneration unit is older than 10 years of age, the efficiency reference values for cogeneration units shall be fixed on the reference values of units of 10 years of age. Therefore, the efficiency reference value for separate production of electricity of Thailand is not appropriate for BPK power plant. The appropriate efficiency reference value for separate production of electricity shall be 32.8% which follow as Annex I, III of commission decision of 21 December 2006 of European committees and based on assumption of 33.2^{o}C of average ambient temperature.

The result found that the Bangpakong power plant had achieved a reference primary energy saving value of 10%. The PES percentage of this existing plant is 25.61%. Also, the PES percentage of the existing plant with three air inlet cooling systems can achieve a reference primary energy saving of 10%.

Table 4.12 Primary energy saving of BPK for 1-year period

	Unit	Existing	Evaporative Cooling	Mechanical Chiller	Absorption Chiller
Fuel					
Fuel energy for gas turbine GT41	MWh	2,491,369	2,529,577	2,674,499	2,674,499
Fuel energy for gas turbine GT42	MWh	2,501,649	2,540,288	2,685,685	2,685,685
Indirect energy from steam to absorption chiller	MWh	-	-	-	240,094
Total fuel energy input	MWh	4,993,018	5,069,865	5,360,184	5,600,278
Electricity					
Electrical output from gas turbine GT 41	MWh	714,098	727,927	783,866	783,866
Electrical output from gas turbine GT42	MWh	718,288	732,285	788,499	788,499
Electrical output from steam turbine ST	MWh	769,186	762,482	726,203	688,356
Total electrical output	MWh	2,201,572	2,222,694	2,298,569	2,260,722
Steam					
CHP useful heat	MWh	-	-	-	240,094
Non-CHP useful heat	MWh	-	-	-	-
Total useful heat energy (q)	MWh	-	-	-	240,094
Overall efficiency (η)	%	44.09	43.84	42.88	44.66
Efficiency of non-combined electrical energy generation	%	44.09	43.84	42.88	41.30
Power to heat ratio		0.742	0.730	0.685	0.617
CHP electrical energy	MWh	-	-	-	148,053
Non-CHP electrical energy	MWh	2,201,572	2,222,694	2,298,569	2,112,669
Fuel energy for non-combined electrical energy generation	MWh	4,993,018	5,069,865	5,360,184	5,115,094
Fuel energy for CHP electrical energy generation	MWh	-	-	-	485,183
Primary Energy Saving	%				
Total heat efficiency, Hη	%	-	-	-	4.29
Total electrical efficiency, Eη	%	44.09	43.84	42.88	40.37
PES (REF Eη=45%, REF Hη=85%)	%	-2.06	-2.64	-4.94	-5.54
PES (REF Eη=32.8%, REF Hη=90%)	%	25.61	25.18	23.51	21.78
CHPHη	%	n/a	n/a	n/a	4.29
CHPEη	%	n/a	n/a	n/a	2.64

CHAPTER 5

CONCLUSIONs AND RECOMMENDATIONs

5.1 Conclusions

This research study looked aimed to improve the performance of existing combined cycle plant, including consideration of cost effectiveness. The reason is that the regulatory process for permitting new generation sources is slow, more demanding of electricity and the combined cycle power plant is the most popular in Thailand. The higher efficiency means less energy consumption or gain power output generation. For the existing plants, some performance enhancement options can also be economically retrofitted to increase power output and efficiency. Heat will generally be used more efficiently, improving the performance but also increasing cost. In practice, a compromise between performance and cost must always be made.

This research work mainly focused on “which alternative is the best solution for improvement of BPK plant performance?” There were four analysis that were used to determine this.

5.1.1 Degradation Analysis

According to GE’s degradation analysis, the degradation of gas turbine normally should comply with the degradation curve in the guarantee test record. The criteria was used to determine the extent of the measured performance. NOI and NHRI of the gas turbine should be better than guaranteed guide or present in positive value. The calculations show that the NOI of gas turbine BPK-C41 is -4.74 %, the NHRI of gas turbine BPK-C41 is -12.68 %, the NOI of gas turbine BPK-C42 is -4.71 % and NHRI of gas turbine BPK-C41 is -12.73 %. As a result, the both of NOI and NHRI were negative. The performance of the Bangpakong combined cycle plant unit 4 cannot achieve the GE’s expected performance or guaranteed performance. It therefore implied to improve performance of gas turbine.

To select the most effective component, both the current performance test data and the initial performance test data are corrected to the same ambient conditions, then compared to the degradation of the combined cycle power plant. The degradation from condenser is highest value of 9.82% and the second is gas turbine BPK-C41 of 8% and BPK-C42 of 8.41%, meanwhile the degradation of all heat exchangers had a small effect on steam turbine output and steam turbine efficiency. Therefore, the first priority of performance improvement is to focus on gas turbine improvement.

5.1.2 Gas Turbine Inlet Cooling System Analysis

The gas turbine is an ambient air-breathing engine, therefore anything affecting the mass flow of the air intake to the compressor will change its performance. The most effective parameter affecting the performance of gas turbine is inlet air temperature therefore the main designs of solutions have focused on the gas turbine inlet cooling system. The simulation model for research analysis process were created, applied and solved on Gate Cycle software of GE manufacturer. Main equipment were implemented including the equipment designed specification, operating data and steam line for the base simulation model of existing plant which was used to be the reference of comparison. The historical climate data of Bangpakong in 2010 was recorded every 10 minutes at site was selected and it was arranged into the seasonably average of hourly weather parameters and used to evaluate the climate. Energy balance and heat balance which consist of temperature, pressure, enthalpy etc. were in small errors for correspondence to the actual operation of an existing plant. After the simulation model was valid, the selected additional systems are evaporative system (high pressure fogging system)**,** mechanical chiller system and absorption chiller system were applied in the Gate cycle model. Then, each system was compared regarding power output enhancement, percentage of heat rate changing and fuel consumption

As a result, the inlet temperature, parasitic load and flue gas temperature is the key factor for improving the performance of the combined cycle power plant. The evaporative system generated the greatest heat rate of the combined cycle power plant. The absorption chiller system generated the greatest power augmentation in which it produced maximum net power augmentation of 11.58 MW, the highest average power improvement is 7.67 MW or 2.5% of existing power. Considering only the gas turbine performance, the evaporative system, mechanical system and absorption chiller increases the gas turbine power output of approximately 2%, 6% and 9.45 % respectively. Considering combined cycle system, the evaporative system, mechanical system and absorption chiller increases the combined cycle power output of approximately 1%, 2% and 2.5% respective.

Although the cooling system had an effect on the larger inlet flow rate and the larger exhaust flow rate in which they increase the performance of gas turbine and heat recovery respectively, it caused a lower exhaust temperature in which heat recovery acquired lower performance. Also, the parasitic load of both chiller systems reduces the power generation of combined cycle plant, and steam extraction for absorption chiller system reduces the power generation of combined cycle plant. The parasitic load is significant for receiving greater performance.

Cost-effectiveness ratio is defined as the investment cost divided by augmented annual power output. It minimizes the investment cost of a given output. The evaporative cooling system provided the greatest of cost effectiveness of 7.18 $/MWh. It therefore supported the evaporative system is the best alternative option for performance improvement for BPK combined cycle power plan. The evaporative cooling system also provided the greatest net present value of US$730,000 which was positive value on given weighted average cost of capital raised for additional fund of 9.1%.

5.1.3 **PES Analysis**

The percentage of PES was used to determine energy utilization. The BPK operates at quite low efficiency. The result shows that the high pressure fogging system has the best primary energy saving value but it cannot achieve a reference primary energy saving value (10%) based on Thailand’s standard reference efficiency (85% and 45% for separate production of heat and electricity respectively) which have been used presently for VSPP. Also PES cannot be improved by adding the inlet cooling systems which are high pressure fogging system, mechanical system and absorption chiller system by extraction steam from low pressure steam turbine. The PES reduces 0.58% from -2.06 % to -2.64 % in evaporative cooling system case while mechanical chiller case and absorption chiller case reduce to be -4.94 % and -5.54 % respectively.

Thailand’s standard efficiency reference for the separate production of electricity (45%) was not suitable for the power plant because it did not consider the climatic situation and the year of the construction of the cogeneration unit as Annexes I. And Annex III of the commission decision of 21 December 2006 of the European committees and Annex III of Directive 2004/8/EC. The reasonable efficiency reference for separate production of electricity should be 32.8% for this combined cycle plant (assume average ambient temperature is 33.2%). The new percentage of PES of existing plant, additional of evaporative system, additional of mechanical system and additional of absorption chiller system were 25.61%, 25.18%, 23.51% and 21.78% respectively in which all options can achieve a reference primary energy saving value of 10%.

5.2 Recommendations

Current VSPP regulation schemes in Thailand have been applied in with the EU directives to ensure that support for cogeneration shall be based on the useful heat demand and primary energy savings. It is significant to set up criteria into the right direction under the basic definition for determination and assessment the energy efficiency of the cogeneration production. It is noticed that overall efficiency of Thailand plant is much lower than the overall efficiency target as in EU directive, which is approximately 75-80%, depending on type of plant. The different climatic situation and technology development between Thailand and Europe explain the different efficiency. To ensure the authenticity of primary energy saving assessment, Thailand current standard efficiency reference, which is 45%, for separate production of electricity for various age and different climatic situation shall be revised based on the consideration of a year of construction of each plant and corrected to climatic condition.

As shown in this research, the parasitic load supply for a chiller system or other additional options is the most significant and affects the energy consumption. The possibility of enhancement of performance would be high to achieve high efficiency combined cycle power plant, the additional technology should be carefully selected from the low parasitic load.

Recommendations for future

This model can help engineers or operators to study other new alternatives for the development of performance, such as an absorption chiller with new GT, instead of the extraction of low pressure steam, consideration of peak demand at daytime and application of the storage tank to the chiller, which can reduce any parasitic load used in the air inlet cooling system.

For very low efficiency or high heat rate problem, the next study could consider other effects such as air extraction used in the turbine side (loss), new technology for improving mechanical degradation of various parts inside, operating control, loss in each part of the gas turbine and fuel properties to increase efficiency.

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APPENDIX A

CLIMATIC DATA

OF

BANGPAKONG COMBINED CYCLE POWER PLANT

Table A Historical data of ambient temperature at Bangpakong Power Plant

	Ambient Temperature (^{o}C)														
Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Summer	Rainy	Winter
1:00:00 AM	25.1	26.2	27.6	29.0	29.2	28.3	27.7	27.3	27.1	27.0	26.4	26.2	28.6	27.5	26.0
2:00:00 AM	24.7	26.0	27.5	28.7	28.9	28.3	27.6	27.0	27.0	26.8	26.1	25.8	28.4	27.3	25.7
3:00:00 AM	24.2	25.8	27.4	28.5	28.7	28.1	27.5	26.9	26.9	26.6	25.8	25.3	28.2	27.2	25.3
4:00:00 AM	23.8	25.5	27.3	28.3	28.5	27.9	27.9	26.7	26.8	26.4	25.5	25.1	28.0	27.1	25.0
5:00:00 AM	23.6	25.2	27.2	28.1	28.3	28.2	29.1	26.7	26.7	26.3	25.4	24.8	27.9	27.4	24.7
6:00:00 AM	23.2	24.9	27.0	28.0	28.2	29.6	30.0	26.7	26.7	26.2	25.2	24.4	27.7	27.8	24.4
7:00:00 AM	23.0	24.7	26.8	28.4	28.7	30.8	31.1	26.8	27.2	26.6	25.3	24.3	28.0	28.5	24.3
8:00:00 AM	23.8	25.7	27.8	30.2	30.3	31.5	31.7	27.7	28.4	27.7	26.1	25.3	29.4	29.4	25.2
9:00:00 AM	25.1	27.5	29.2	31.8	31.8	32.1	32.4	29.1	30.0	28.3	27.1	27.1	30.9	30.4	26.7
10:00:00 AM	26.4	29.4	30.7	33.1	33.0	32.8	32.6	30.0	30.8	29.3	28.0	28.3	32.3	31.1	28.0
11:00:00 AM	27.7	30.5	31.3	33.8	33.3	33.3	32.0	30.8	31.8	29.9	29.0	29.2	32.8	31.6	29.1
12:00:00 PM	28.8	30.8	31.7	34.0	33.8	33.5	31.0	31.4	31.9	30.8	29.8	30.0	33.2	31.7	29.8
1:00:00 PM	29.8	31.3	32.2	34.2	34.0	33.4	31.2	31.5	32.1	31.1	30.5	30.9	33.5	31.9	30.6
2:00:00 PM	30.7	31.4	32.6	34.1	33.9	33.1	31.1	31.4	31.9	30.9	31.1	31.1	33.5	31.7	31.0
3:00:00 PM	31.1	30.9	32.8	34.0	33.7	32.8	30.7	31.2	31.6	30.5	31.3	31.5	33.5	31.3	31.2
4:00:00 PM	31.3	30.7	32.7	33.6	33.5	32.3	30.3	30.8	31.3	30.0	31.3	31.5	33.3	31.0	31.2
5:00:00 PM	30.9	30.5	32.5	33.4	33.1	31.8	29.9	30.5	30.7	29.2	30.8	30.4	33.0	30.4	30.6
6:00:00 PM	29.6	29.4	31.9	32.5	32.6	31.2	29.7	29.8	29.9	28.4	29.6	29.3	32.3	29.8	29.5
7:00:00 PM	28.3	28.3	31.0	31.4	31.8	30.4	29.1	28.8	29.0	28.1	28.7	28.6	31.4	29.1	28.5
8:00:00 PM	27.6	28.0	30.2	31.0	31.2	29.8	28.9	28.5	28.7	27.8	28.3	28.2	30.8	28.7	28.0
9:00:00 PM	27.3	27.8	29.6	30.4	30.6	29.6	28.6	28.4	28.4	27.8	27.9	27.8	30.2	28.6	27.7
10:00:00 PM	26.8	27.4	29.2	29.9	30.1	29.3	28.6	28.0	28.1	27.7	27.5	27.4	29.7	28.3	27.3
11:00:00 PM	26.2	27.0	28.9	29.5	29.8	29.0	28.0	27.9	27.7	27.4	27.2	27.0	29.4	28.0	26.8
12:00:00 AM	25.3	26.5	28.5	29.3	29.7	27.5	27.5	27.7	27.4	27.5	27.0	26.5	29.2	27.5	26.3

Table B Historical data of Relative Humidity at Bangpakong Power Plant

	Relative Humidity (%)														
Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Summer	Rainy	Winter
1:00 AM	68.8	79.3	78.7	80.4	82.4	81.7	84.1	85.6	87.6	85.3	74.3	76.9	80.5	84.9	74.9
2:00 AM	69.2	80.8	81.4	81.7	83.2	83.0	84.8	85.8	88.3	85.9	75.6	78.3	82.1	85.6	76.0
3:00 AM	69.6	81.7	82.5	83.0	84.1	83.1	85.3	86.7	88.6	86.8	76.4	79.9	83.2	86.1	76.9
4:00 AM	71.4	83.1	83.6	84.3	85.2	83.0	86.1	87.2	88.8	87.2	77.0	80.7	84.4	86.4	78.0
5:00 AM	71.4	84.4	83.9	85.6	86.5	83.8	86.4	87.4	89.1	87.2	76.4	82.1	85.3	86.8	78.6
6:00 AM	72.8	85.6	85.3	86.2	87.6	84.5	87.1	87.4	89.5	88.0	76.0	82.7	86.4	87.3	79.3
7:00 AM	72.8	86.5	85.1	84.2	85.3	83.4	87.1	87.6	88.1	87.1	75.0	82.1	84.9	86.7	79.1
8:00 AM	67.6	83.0	78.0	75.7	77.5	76.6	82.4	85.0	82.0	81.0	69.3	76.3	77.0	81.4	74.0
9:00 AM	61.5	74.6	69.0	67.6	69.2	71.9	76.5	79.3	75.5	76.5	64.5	67.5	68.6	76.0	67.0
10:00 AM	56.8	65.0	61.8	62.8	63.3	68.0	70.5	73.3	71.4	71.9	60.3	62.5	62.6	71.0	61.2
11:00 AM	53.0	62.1	60.0	61.9	63.9	65.1	66.6	69.6	67.6	69.6	57.3	57.9	61.9	67.7	57.6
12:00 PM	50.5	59.1	58.7	61.3	62.1	62.8	63.4	66.9	66.5	67.2	55.2	55.6	60.7	65.4	55.1
1:00 PM	47.8	58.7	57.6	59.7	61.5	61.2	63.1	66.5	65.5	65.5	52.9	53.6	59.6	64.3	53.3
2:00 PM	45.7	58.9	57.4	59.5	60.7	60.5	65.9	68.0	66.4	67.8	52.3	52.9	59.2	65.7	52.5
3:00 PM	44.6	60.5	58.2	58.9	63.7	60.9	70.3	67.7	67.5	69.2	52.3	52.7	60.2	67.1	52.5
4:00 PM	45.0	59.7	60.8	59.5	63.3	61.6	69.8	69.1	69.1	71.3	53.0	55.5	61.2	68.2	53.3
5:00 PM	47.5	63.0	60.6	61.7	64.6	63.9	69.5	71.0	71.6	75.0	56.1	60.7	62.3	70.2	56.8
6:00 PM	53.2	68.1	62.7	65.3	67.0	65.5	71.3	73.6	74.3	77.9	61.2	64.9	65.0	72.5	61.9
7:00 PM	58.0	71.4	64.4	69.3	69.5	67.9	72.8	78.1	77.8	79.5	65.2	67.8	67.7	75.2	65.6
8:00 PM	59.7	72.3	67.2	70.3	71.4	70.8	74.2	79.6	80.7	81.0	67.7	69.4	69.6	77.3	67.3
9:00 PM	60.6	73.3	69.6	72.5	74.8	74.5	76.1	80.8	82.4	81.7	69.2	71.5	72.3	79.1	68.7
10:00 PM	62.8	75.3	71.7	74.7	77.2	77.6	78.3	82.5	83.8	82.4	70.0	73.2	74.5	80.9	70.3
11:00 PM	65.0	77.3	73.3	76.8	78.6	78.2	80.4	83.4	85.4	83.5	71.6	74.2	76.2	82.2	72.1
12:00 AM	67.6	78.9	75.4	78.6	80.2	79.7	82.6	84.2	86.3	84.7	72.7	76.5	78.1	83.5	73.9

APPENDIX B

DETAILS OF

BANGPAKONG COMBINED CYCLE POWER PLANT BLOCK 4

AND CURRENT PERFORMANCE TEST DATA

Details Of Machines & Equipments Use In
Bang Pakong Combine Cycle Plant Block 3&4

Combustion Turbine
Component - Equipment Data

Technical Data

Axial Flow Compressor	*17 Stages With Modulating Inlet Guide Vanes And First Stages Are Ni-Co Coated*
Turbine	*3 Stages (Second & Third Stage Incorporating And Integral Tip Shroud*
Speed	*3,000 RPM.*
Number Of Combustion Chamber	*14*
Fuel Nozzle	*14*
Spark Plug	*2 (Chamber 12,13)*
Flame Detector	*4 (Chamber 4,5,10,11)*
Cooled Nozzle & Bucket	*Nozzle Stage 1,2* *Bucket Stage 1,2*
Turbine Blade Coating	*First Stage Bucket (RT22)*
Turbine Control System	*Speedtronic Mark IV*
Manufacture	*General Electric*

Performance In Simple Cycle Mode :

(ISO.Condition - 15$^{?}$C Amb.Temp., 1.013 Bar , 60 %RH

Design Point

Air Flow 1,450 Ton/Hr.

Turbine Inlet Temp. 1104$^{?}$C (Base) 1160$^{?}$C (Peak)

Turbine Exhaust Temp. 529$^{?}$C (Base) 565$^{?}$C (Peak)

Output (MW.)

	GAS	Light Oil
Base	*116.4*	*114.2*
Peak	*125.7*	*123.3*

Consumption

@ HV.Gas = 32,000 Kj/m^3
HV.Oil = 43,050 Kj/Kg

Base : 39,722 Nm^3/Hr. (Gas) , 29,206 Kg/Hr. (Light Oil)
Peak : 42,788 Nm^3/Hr. (Gas) , 31,419 Kg/Hr. (Light Oil)

Heat Rate (Kj/Kwh.) At LHV.

Base : 10,880 (Gas) , 10,970 (Light Oil)
Peak : 10,840 (Gas) , 10,930 (Light Oil)

Combustion Turbine Generator

Technical Data

Rated Output	*128,600 KVA. (Capability With One Half Cooler Section Out Of Service 80 %Rating)*
Rated Voltage	*11.5 KV.*
Frequency	*50 H$_z$*
Power Factor	*0.85*
Cooling	*Hydrogen Cooled*
Armature Current	*6,456 A.*
Field Current	*1,158 A.*
Excitation Voltage	*500 V.*
Max.Temp.Armature	

	109?C
Max.Temp.Field	*115?C*
Max.Cold Gas	*40?C*
Manufacture	*General Electric*

Gas Turbine Name Plate Data

General Electric

No. :

Base : 103,750 kw. Peak : 113,188 kw. Fuel : Natura Gas

Turbine Exhaust : 540?C Press. :14.0 H_2O

CPRSR : Stages 17 RPM : 3,000

Power Turbine : Stages 3 RPM : 3,000

Base : 102,760kw. Peak : 112,060 kw. Fuel : Distillate

Heat Recovery Steam Generators

1. Number Furnished	*Two Per Block*
2. Manufacture	*Cockerill Mechanical Industries*
3. Type	*Dual Pressure Waste Heat (Combustion Turbine Exhaust) Boiler With Assisted Circulation*
4. Steaming Capability	*(a) Design Capacity (CT.Firing Natural Gas) - 166,802 Kg/Hr. High Pressure Main Steam - 39,765 Kg/Hr. Low Pressure Steam (b) Design Capacity (CT.Firing Distillate Oil) - 166,420 Kg/Hr. High Pressure Main Steam - 40,488 Kg/Hr. Low Pressure Steam*
5. Operating Pressure	*(a) High Pressure Main Steam - 82.44 Bar (CT.Firing Natural Gas) - 82.44 Bar (CT.Firing Distillate Oil) (b) Low Pressure Steam - 8.5 Bar (CT.Firing Natural Gas) - 8.3 Bar (CT.Firing Distillate Oil)*
6. Drum Design Pressure	*(a) High Pressure Drum 96.99 Bar (b) Low Pressure Drum 11.99 Bar*
7. Steam Temperature	*(a) High Pressure Superheat Outlet - 512?C (CT.Firing Natural Gas) - 511?C (CT.Firing Distillate Oil) (b) Low Pressure Superheat Outlet - 235.0?C (CT.Firing Natural Gas) - 236.5?C (CT.Firing Distillate Oil)*
8. Total Heating Surface	*75,062 m^2*
(a) HP.Economizer	*27,888 m^2*
(b) HP.Evaporator	*22,207 m^2*
(c) HP.Superheater	*7,229 m^2*
(d) LP.Economizer	*3,123 m^2*

(e) LP.Evaporator	*13,882 m^2*
(f) LP.Superheater	*733 m^2*
9. Design CT.Exhaust Gas Flow Rate	*(a) 1,361,587 Kg/Hr. (CT.Firing Natural Gas)* *(b) 1,366,560 Kg/Hr. (CT.Firing Distillate Oil)*

Steam Turbine

Rating And Design Data

1. Type Of Turbine	*Tandem Compound 2 Cylinders 2 Flow Exhaust Turbine*
2. Rated Output	*109,000 kw.*
3. Rated Speed	*3,000 rpm.*
4. Direction Of Revolution	*Counter-Clock-Wise (Seeing From Turbine End)*
5. Steam Conditions	*HP.Steam Pressure 80.0 ata.(78.5 Bar) , Temp. 509 ? C* *LP.Steam Pressure 9.1 ata.(7.0 Bar) , Temp. 232 ? C*
6. Exhaust Vacuum	*63 mmHg abs*
7. Number Of Stage	*HP.Turbine : 16 Stages* *LP.Turbine : 6 Stages , 2 Flow* *Number Of Wheel : 28*
8. Manufacuring	*Toshiba*

Steam Turbine Generator

Generator Disign Data

1. Type	*Takl*
2. Rated Output	*145,000 KVA.*
3. Rated Voltage	*13.8 KV.*
4. Armature Current	*6,067 A.*
5. Frequency	*50 Hz*
6. Speed	*3,000 rpm.*
7. Power Factor	*0.85*
8. Number Of Poles	*2*
9. Excitation	*Brushless*
10. Cooling	*Hydrogen Cooled (Pressure 206 kpa.)*
11. Manufacturing	*Toshiba*

BANGPAKONG COMBINED CYCLE POWER PLANT BLOCK 3-4

PERFORMANCE TEST

UNIT : BG.401 (COMBINED CYCLE)
DATE : 20/08/2010 (10:30)

NO.	DESCRIPTION	VALUE	UNIT
1.	GROSS POWER OUTPUT TEST	97541.15	KW
2.	FUEL GAS FLOW	1207485.75	CF/H
3.	FUEL GAS HEATING VALUE	1021.02	KJ/CF
4.	FUEL GAS HEAT CONSUMPTION	1232.87	GJ
5.	GROSS HEAT RATE TEST	12639.489	KJ/KWH
6.	GROSS EFFICIENCY TEST	28.482	%
7.	GROSS POWER OUTPUT CORR.	97,881.03	KW
8.	GROSS HEAT RATE CORR.	12689.376	KJ/KWH
9.	GROSS EFFICIENCY CORR.	28.370	%

TEST DATA and CALCULATION 99,283.99 98,598.69 (corrected to 32.2C)

NO.	DESCRIPTION	VALUE	UNIT
1.	BAROMETRIC PRESS.	1.01000	BAR
2.	SPECIFIC HUMIDITY	0.53000	KG/KG
3.	DIFF. PRESS. AIR FILTER	1.969	inH2O
4.	INLET GUIDE VANE OPEN	84.011	DEG
5.	COMPRESSOR INLET TEMP.	33.346	C
6.	COMP. DISCHARGE TEMP.	364.273	C
7.	COMP. DISCHARGE PRESS.	10.218	BAR
8.	COMP. RATIO	11.176	-
9.	COMP. EFFICIENCY	91.972	%
10	EXHAUST GAS TEMP.	554.444	C
11	EXHAUST GAS ENERGY	859.491	GJ
12	EQUIVALENT FIRED HOUR	27150	HOURS
	EXHAUST GAS PRESSURE	0.03342	Bar

CORRECTION FACTOR 0

NO.	DESCRIPTION	OUT PUT	HEAT RAT
1.	BAROMETRIC PRESS.	0.9973	0.9996
2.	COMP. INLET TEMP.	0.9916	1.0011
3.	SPECIFIC HUMIDITY	1.0007	0.9977
4.	FUEL TEMP	0.9999	0.9999
5.	INLET PRESS DROP	1.007	0.9978

NOTE : 25 DEC.C ; 760 mmHg ; 75 %RH FIRED HOURS - -

FH.from 2nd MO (at 7 Oct 2005)@90,800.90 Hrs.

BANGPAKONG COMBINED CYCLE POWER PLANT BLOCK 3-4

PERFORMANCE TEST

UNIT : BG.402 (COMBINED CYCLE)
DATE : 20/08/2010 (10:30)

NO.	DESCRIPTION	VALUE	UNIT
1.	GROSS POWER OUTPUT TEST	98127.90	KW
2.	FUEL GAS FLOW	1212721.31	CF/H
3.	FUEL GAS HEATING VALUE	1021.02	KJ/CF
4.	FUEL GAS HEAT CONSUMPTION	1238.22	GJ
5.	GROSS HEAT RATE TEST	12618.388	KJ/KWH
6.	GROSS EFFICIENCY TEST	28.530	%
7.	GROSS POWER OUTPUT CORR.	97,742.41	KW
8.	GROSS HEAT RATE CORR.	12695.124	KJ/KWH
9.	GROSS EFFICIENCY CORR.	28.357	%

TEST DATA and CALCULATION 99,133.01 98,448.76 (corrected to 32.2C)

NO.	DESCRIPTION	VALUE	UNIT
1.	BAROMETRIC PRESS.	1.01000	BAR
2.	SPECIFIC HUMIDITY	0.54000	KG/KG
3.	DIFF. PRESS. AIR FILTER	1.968	inH2O
4.	INLET GUIDE VANE OPEN	83.992	DEG
5.	COMPRESSOR INLET TEMP.	32.351	C
6.	COMP. DISCHARGE TEMP.	371.365	C
7.	COMP. DISCHARGE PRESS.	10.392	BAR
8.	COMP. RATIO	11.349	-
9.	COMP. EFFICIENCY	90.275	%
10	EXHAUST GAS TEMP.	553.474	C
11	EXHAUST GAS ENERGY	862.629	GJ
12	EQUIVALENT FIRED HOUR	29728	HOURS
	EXHAUST GAS PRESSURE	0.03322	Bar
		0	

CORRECTION FACTOR

NO.	DESCRIPTION	OUT PUT	HEAT RAT
1.	BAROMETRIC PRESS.	0.9973	0.9996
2.	COMP. INLET TEMP.	0.9990	0.9989
3.	SPECIFIC HUMIDITY	1.0007	0.9978
4.	FUEL TEMP	0.9999	0.9999
5.	INLET PRESS DROP	1.007	0.9978

NOTE : 25 DEC.C ; 760 mmHg ; 75 %RH FIRED HOURS - -

FH.from 2nd MO (at 13 Apr 2005)@90,835 Hrs.

BANGPAKONG COMBINED CYCLE POWER PLANT BLOCK 3-4

PERFORMANCE TEST

UNIT : BC.403
DATE : 20/08/2010 (10:30)

NO.	DESCRIPTION	VALUE	UNIT
1.	GROSS POWER OUTPUT TEST	108900.00	KW
2.	HEAT CONSUMPTION	1108.3565	GJ/HR
3.	GROSS HEAT RATE TEST	10177.75	KJ/KWH
4.	GROSS EFFICIENCY TEST	35.371	%
5.	GROSS POWER OUTPUT CORR.	107915.96	KW
6.	GROSS HEAT RATE CORR.	10208.63	KJ/KWH
7.	GROSS EFFICIENCY CORR.	35.264	%

TEST DATA

NO.	DESCRIPTION	VALUE	UNIT
1.	HP. MAIN STEAM PRESS.	74.11	BAR A
2.	HP. MAIN STEAM TEMP.	522.00	C
3.	HP. MAIN STEAM ENTHALPY	3459.70	KJ/HG
4.	LP. STEAM PRESS.	9.56	BAR A
5.	LP. STEAM TEMP.	233.60	C
6.	LP. STEAM ENTHALPY	2912.20	KJ/KG
7.	HP. FEED WATER PRESS.	79.51	BAR A
8.	HP. FEED WATER TEMP.	103.05	C
9.	HP. FEED WATER ENTHALPY	437.79	KJ/KG
10	HP. FEED WATER FLOW	333563.00	KG/HR
11	LP. FEED WATER PRESS.	21.81	BAR A
12	LP. FEED WATER TEMP.	100.05	C
13.	LP. FEED WATER ENTHALPY	420.85	KJ/KG
14.	LP. FEED WATER FLOW	67613.00	KG/HR
15.	LP. STEAM TO DEA. FLOW	23381.00	KG/HR
16.	CONDENSER PRESS.	57.04	mmHg

CORRECTION FACTOR

NO.	DESCRIPTION	OUT PUT	HEAT RAT
1.	INDUCTION STEAM FLOW	0.99220	1.00540
2.	INDUCTION STEAM ENTHALPY	1.00012	1.00004
3.	INITIAL STEAM TEMP.	1.01331	0.99520
4.	INITIAL STEAM PRESS.	0.99631	1.00477
5.	VALVE LOOP	1.00593	0.99375
6.	CONDENSER PRESS.	1.00135	0.99787

Service Hour = 14925 from 2nd MO(5April2008)

Bang Pakong Combined Cycle Block 4

Condenser Performance Test

Test date : 20/08/2010 st Load : 108.90 MW

Item	Description	Units	Value
1	No. of CW. Passes		2.00
2	No. of Tube (design)		14,020.00
3	No. of Tube (test)		13,990.00
4	Tube outside diameter	mm	25.40
5	Tube wall thickness	mm	1.10
6	Tube material		Titanuim
7	Tube surface area (design)	m^2	10,912.00
8	CW. Flow area in tubes (test)	m^2	2.96
9	Tube surface area (test)	m^2	10,888.65
10	Electrical load	kW	108,900.00
11	Average CW. Inlet temperature (test)	^{o}C	29.38
12	Average CW. outlet temperature (test)	^{o}C	38.28
13	CW. Temperature rise	^{o}C	8.91
14	Abs. Conderser pressure (test)	mbar	79.44
15	Heat capacity	kJ/m^{3}C	4,120
16	Turbine heat rate (test)	kJ/kWh	9,852.15
17	Condenser heat load (steam side, test)	kW	187,276.21
18	CW. Flow rate (test)	m^3/s	5.1026
19	CW. Velocity (test)	m/s	1.73
20	Saturated temperature (test)	^{o}C	41.40
21	Log Mean Temp. Dif. (test)	^{o}C	6.60
22	Test heat transfer coefficient (Ut), heat balance	kW/m^{2}C	2.607
23	CW. Velocity in tube at inlet condition (V)	m/s	2.13
24	Dimensional factor depending upon tube outer diameter (C1)	kW/m^{2}C	2.582
25	Dimensional correction factor for CW. Inlet temperature (C2)	-	1.101
26	Dimentionless correction factor for tube material and gauge (C3)	-	0.81
27	dimensionless cleanliness factor (C4)	-	0.90
28	Design overall heat transfer coefficient (Ud)	kW/m^{2}C	3.02
29	*Cleanliness factor by Ut, heat balance*	-	*86.20*

Service Hour :from 2rd MO(5April2008)	14925	hr
Diff. Water Box (Side A / SideB)	0.2/0.3	BAR
Forebay Level	6.7	m

APPENDIX C

BPK–CC BLOCK 4 SIMULATION MODEL

Table C: Main input data for an existing plant simulation model

Sources/Equipments	**Input Data/Setting**
Ambient Conditions	
Temperature (DB)	91.00 F
Pressure	14.65 psia
Humidity	0.6247
Steam Property Method	1993 ASME steam property formula
Gas Property Method	JANAF Table data curves
Gas Turbine (GT1)	
Calculation Method	Curve Driven
Curve Table File Name	GE91E3
Part Load Method	Base Load
Lower Heating Value	15000 BTU/lb
Inlet Air	Nitrogen 0.7569 Oxygen 0.2031 Carbon Dioxide 0.000319861 H2O 0.0307231 Argon 0.00904335 H/C Ratio 4 Molecular Weight 28.63
Fuel	Nitrogen 0.1383 Carbon Dioxide 0.0474 Hydro carbons 0.8143 H/C Ratio 3.7354 Molecular Weight 18.81
Inlet Press. Drop	5.0516 in H2O
HRSG Press. Drop	12.04 in H2O
Degradation Net Power Multiplier	0.9300
Degradation Net Heat Rate Multiplier	1.1505
Gas Turbine (GT2)	
Calculation Method	Curve Driven
Curve Table File name	GE91E3

Sources/Equipments	Input Data/Setting
Part Load Method	Base Load
Lower Heating Value	15000 BTU/lb
Inlet Air	Nitrogen 0.7569
	Oxygen 0.2031
	Carbon Dioxide 0.000319861
	H2O 0.0307231
	Argon 0.00904335
	H/C Ratio 4
	Molecular Weight 28.63
Fuel	Nitrogen 0.1383
	Carbon Dioxide 0.0474
	Hydro carbons 0.8143
	H/C Ratio 3.7354
	Molecular Weight 18.81
Inlet Press. Drop	5.0516 in H2O
HRSG Press. Drop	12.04 in H2O
Degradation Net Power Multiplier	0.9245
Degradation Net Heat Rate Multiplier	1.1525
Steam Turbine (ST1)	
Design Efficiency Method	Isentropic Expansion Efficiency
User-Input Efficiency	0.9000
Design Press. Method	Throttle Pressure Set Upstream
Design Extraction Press. Method	Input Extraction Pressures
Rotational Speed	3000
Default Stage Press. Ratio	0.8000
Design Blade Flow Angle	15.00
Min. Allowed Exit Quality	0.8500
Max. Allowed Inlet Temp.	1050.0 F
Current Overall Efficiency	0.8956
Cur. Bowl-Last Extraction Eff.	0.9000
Cur. Bowl-ELEP Eff.	0.9000

Sources/Equipments	Input Data/Setting
Current Inlet S.V.	0.6744 ft^3/lb
Current Bowl Pressure	1164.9 psia
Group Stage 1 eff.	0.9000
Group Stage 1 Current PR	0.0517409
Group 1	13 Stages
Design Stage PR Group 1	0.7963
Group 1 Stage Critical PR	0.0281223
Group Stage 1 Flow Coeff.	17509
Steam Turbine (ST2)	
Design Efficiency Method	Isentropic Expansion Efficiency
User-Input Efficiency	0.8290
Design Press. Method	Throttle Pressure Set Upstream
Design Extraction Press. Method	Input Extraction Pressures
Rotational Speed	3000
Default Stage Press. Ratio	0.8000
Design Blade Flow Angle	15.00
Min. Allowed Exit Quality	0.8500
Max. Allowed Inlet Temp.	1050.0 F
Current Overall Efficiency	0.8249
Cur. Bowl-Last Extraction Eff.	0.8249
Cur. Bowl-ELEP Eff.	0.8249
Current Inlet S.V.	7.60684 ft^3/lb
Current Bowl Pressure	59.07 psia
Group Stage 1 eff.	0.8290
Group Stage 1 Current PR	0.021452
Group 1	17 Stages
Design Stage PR, Group 1	0.7977
Group 1 Stage Critical PR	0.0118744
Group Stage 1 Flow Coeff.	294096
Condenser (CND1)	
Condenser Modelling Method	Surface Area

Sources/Equipments	Input Data/Setting
Surface Area	117205 ft^2
CW Method Flag	Input Cooling Water Data
Design HTC Calculation Method	User Input Values for U
HEI Cleanliness Factor	0.85
Min. Allowed Press.	0.25 psia
Max. Allowed Press.	25.00 psia
Condenser Pump (CNDPMP)	
Control Method Flag	Fixed Control Valve Outlet Press.
Control Valve Outlet Pressure	150 psi
Efficiency Method Flag	Input Efficiency
Isentropic Efficiency	0.85
Rated Flow Method Flag	Rated Mass Flow
Rated Mass Flow Rate	915008 lb/hr
CNDSP	
Steam ID at Primary Port	LPFW
Primary Port Control Method	Down Steam Flow Control
Steam ID at Secondary Port	HPFW
Secondary Port Control Method	Down Steam Flow Control
Deaerator (DA1)	
DA Method Flag	Automatic pegging, demand flow
Desired Operating Press.	20.72 psia
Generator (GEN1)	
Generator Efficiency Method Flag	Specified Generator Efficiency
Overall Generator Efficiency	0.9850
Generator Rating (kVA)	50000
Rating Coolant Pressure	30.00 psia
Generator RPM	3000.0
Header (HDR1)	
First Outlet Control Flag	Overflow Port
First Outlet Desired Mass Fraction	0.5298
Seventh Outlet Control Flag	Downstream Flow Control

Sources/Equipments	**Input Data/Setting**
Seventh Outlet Desired Mass Frac.	0.4702
Demand Flow Control Flag	Yes
Desired Outlet Flow	80889 lb/hr
High Pressure Economizer (HP1EC1)	
Economizer Modeling Method	Surface Area
Surface Area	150092 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	10.16 BTU/hr-ft^2-F
Number of HTX Passes	10
High Pressure Economizer (HP1EC2)	
Economizer Modeling Method	Surface Area
Surface Area	150092 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	3.61117 BTU/hr-ft^2-F
Number of HTX Passes	10
High Pressure Evaporator (HP1EV)	
Evaporator Method Flag	Surface Area
Surface Area	239034 ft^2
Pressure Method Flag	Send Operating Pressure Upstream
Calculated Operating Pressure	1210.4 psia
Blowdown Method Flag	Fraction of boiler feedwater
Blowdown as BFW Fraction	0.01
Overall Heat Transfer Coeff.	6.59685 BTU/hr-ft^2-F
High Pressure Superheater (HP1SH1)	
Superheater Method Flag	Surface Area
Surface Area	38906 ft2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	9.63645 BTU/hr-ft^2-F

Sources/Equipments	**Input Data/Setting**
Cp Calculation Method	Integrated
Number of HTX Passes	10
High Pressure Superheater (HP1SH2)	
Superheater Method Flag	Surface Area
Surface Area	38906 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	8.66749 BTU/hr-ft^2-F
Cp Calculation Method	Integrated
Number of HTX Passes	10
High Pressure Economizer (HP2EC1)	
Economizer Modeling Method	Surface Area
Surface Area	150092 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	9.89784 BTU/hr-ft^2-F
Number of HTX Passes	10
High Pressure Economizer (HP2EC1)	
Economizer Modeling Method	Surface Area
Surface Area	150092 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	2.92279 BTU/hr- ft^2-F
Number of HTX Passes	10
High Pressure Evaporator (HP2EV)	
Evaporator Method Flag	Surface Area
Surface Area	239034 ft^2
Pressure Method Flag	Send Operating Pressure Upstream
Calculated Operating Pressure	1210.4 psia
Blowdown Method Flag	Fraction of boiler feedwater
Blowdown as BFW Fraction	0.01

Sources/Equipments	**Input Data/Setting**
Overall Heat Transfer Coeff.	6.14055 BTU/hr- ft^2-F
High Pressure Superheater (HP2SH1)	
Superheater Method Flag	Surface Area
Surface Area	38906 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	9.37504 BTU/hr- ft^2-F
Cp Calculation Method	Integrated
Number of HTX Passes	10
High Pressure Superheater (HP2SH2)	
Superheater Method Flag	Surface Area
Surface Area	38906 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	8.68298 BTU/hr- ft^2-F
Cp Calculation Method	Integrated
Number of HTX Passes	10
High Pressure Boiler Feed Pump (HPBFP1)	
Control Method Flag	Fixed Control Valve Outlet Press
Desired Control Valve Outlet Pressure	1255.4 psia
Pump Exit Pressure Method Flag	Pressure Difference (Pump Exit - Control Valve Exit
Efficiency Method Flag	Input Efficiency
Desired Isentropic Efficiency	0.8500
Rated Flow Method Flag	Rated Mass Flow
Rated Mass Flow Rate	915008 lb/hr
High Pressure Boiler Feed Pump (HPBFP2)	
Control Method Flag	Fixed Control Valve Outlet Press
Desired Control Valve Outlet Pressure	1255.4 psia
Pump Exit Pressure Method Flag	Pressure Difference (Pump Exit - Control Valve Exit

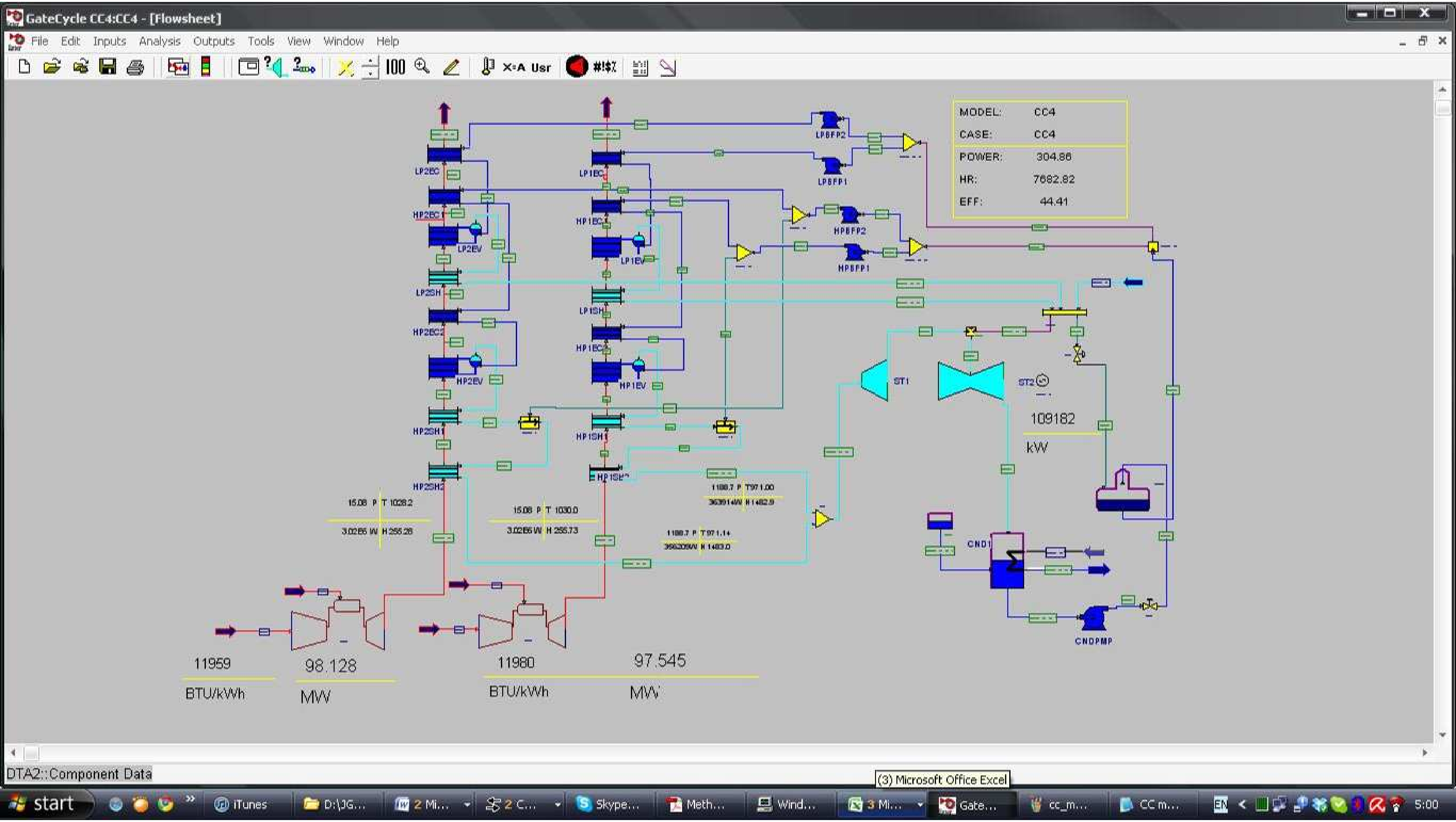
Sources/Equipments	**Input Data/Setting**
Efficiency Method Flag	Input Efficiency
Desired Isentropic Efficiency	0.8500
Rated Flow Method Flag	Rated Mass Flow
Rated Mass Flow Rate	915008 lb/hr
HPFWSP	
Stream ID at Primary Port	S35
Primary Port Control Method	downstream flow control
Stream ID at Tertiary Port	S34
Tertiary Port Control Method	downstream flow control
HPSP1	
Stream ID at Primary Port	S17
Primary Port Control Method	downstream flow control
Stream ID at Tertiary Port	S18
Tertiary Port Control Method	downstream flow control
HPSP2	
Stream ID at Primary Port	S11
Primary Port Control Method	downstream flow control
Stream ID at Tertiary Port	S46
Tertiary Port Control Method	downstream flow control
Low Pressure Economizer (LP1EC)	
Economizer Modeling Method	Surface Area
Surface Area	33616 ft2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	4.96323 BTU/hr- ft^2-F
Number of HTX Passes	10
Low Pressure Evaporator (LP1EV)	
Evaporator Method Flag	Surface Area
Surface Area	149425 ft2
Pressure Method Flag	Send Operating Pressure Upstream
Calculated Operating Pressure	137.97 psia

Sources/Equipments	**Input Data/Setting**
Blowdown Method Flag	Fraction of boiler feedwater
Blowdown as BFW Fraction	0.01
Overall Heat Transfer Coeff.	3.82332 BTU/hr- ft^2-F
Low Pressure Superheater (LP1SH1)	
Superheater Method Flag	Surface Area
Surface Area	7889.9 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	4.87561 BTU/hr- ft^2-F
Cp Calculation Method	Integrated
Number of HTX Passes	10
Low Pressure Economizer (LP2EC)	
Economizer Modeling Method	Surface Area
Surface Area	33616 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff
Overall Heat Transfer Coeff.	4.97173 BTU/hr- ft^2-F
Number of HTX Passes	10
Low Pressure Evaporator (LP2EV)	
Evaporator Method Flag	Surface Area
Surface Area	149425 ft^2
Pressure Method Flag	Send Operating Pressure Upstream
Calculated Operating Pressure	137.97 psia
Blowdown Method Flag	Fraction of boiler feedwater
Blowdown as BFW Fraction	0.01
Overall Heat Transfer Coeff.	3.32476 BTU/hr- ft^2-F
Low Pressure Superheater (LP2SH)	
Superheater Method Flag	Surface Area
Surface Area	7889.9 ft^2
Configuration Method	Cross-Counter, 1 Tube Row / Pass
Design UA Method	Specify HT Coeff

Sources/Equipments	**Input Data/Setting**
Overall Heat Transfer Coeff.	4.36414 BTU/hr -ft^2-F
Cp Calculation Method	Integrated
Number of HTX Passes	10
Low Pressure Boiler Feed Pump (LPBFP1)	
Control Method Flag	Fixed Control Valve Outlet Press
Desired Control Valve Outlet Pressure	162.97 psia
Pump Exit Pressure Method Flag	Pressure Difference (Pump Exit - Control Valve Exit
Efficiency Method Flag	Input Efficiency
Desired Isentropic Efficiency	0.8500
Rated Flow Method Flag	Rated Mass Flow
Rated Mass Flow Rate	915008 lb/hr
Low Pressure Boiler Feed Pump (HPBFP2)	
Control Method Flag	Fixed Control Valve Outlet Press
Desired Control Valve Outlet Pressure	162.97 psia
Pump Exit Pressure Method Flag	Pressure Difference (Pump Exit - Control Valve Exit
Efficiency Method Flag	Input Efficiency
Desired Isentropic Efficiency	0.8500
Rated Flow Method Flag	Rated Mass Flow
Rated Mass Flow Rate	915008 lb/hr
LPFWSP	
Stream ID at Primary Port	S31
Primary Port Control Method	downstream flow control
Stream ID at Tertiary Port	S32
Tertiary Port Control Method	downstream flow control
M1	
Stream ID at Primary Port	HPSTM2
Stream ID at Tertiary Port	HPSTM1
M2	
Stream ID at Primary Port	S19

Sources/Equipments	**Input Data/Setting**
Stream ID at Tertiary Port	LPSTM
Makeup (MU1)	
Makeup Block Type	Automatic
Air Inlet (S33)	
Calculation (flash) Method	Pressure - Temperature
Use Default Ambient Air Flag	Yes
Air Inlet (S36)	
Calculation (flash) Method	Pressure - Temperature
Use Default Ambient Air Flag	Yes
Fuel (S51)	
Calculation (flash) Method	Pressure - Temperature
Fuel Type	User Defined Gas
Lower Heating Value	15000 BTU/lb
Dew Point Temperature	-459.67 F
Fuel (S52)	
Calculation (flash) Method	Pressure - Temperature
Fuel Type	User Defined Gas
Lower Heating Value	15000 BTU/lb
Dew Point Temperature	-459.67 F
Temperature Control Mixer (TMX1)	
Press. Control Method	Pressure Drop
Pressure Drop	-7.25188 psi
Temperature Control Mixer (TMX1)	
Press. Control Method	Pressure Drop
Pressure Drop	-7.25188 psi
Valve (V1)	
Press. Control Method	Specified Outlet Pressure
Desired Exit Pressure	20.72 psia
Inlet Press. Method	Accept Incoming Pressure
Temp. Control Method	No Enthalpy change

Sources/Equipments	**Input Data/Setting**
Valve (V1)	
Press. Control Method	Specified Outlet Pressure
Desired Exit Pressure	20.72 psia
Inlet Press. Method	Accept Incoming Pressure
Temp. Control Method	No Enthalpy change



MODEL: CC4

CASE: CC4

POWER: 304.86

HR: 7682.82

EFF: 44.41

15.08 P T 1028.2
3.02E6 W H 255.28

15.08 P T 1030.0
3.02E6 W H 255.73

1188.7 P T971.00
363914W H 1482.9

1188.7 P T971.14
366209W H 1483.0

109182
kW

11959
BTU/kWh

98.128
MW

11980
BTU/kWh

97.545
MW

Existing Performance Summary

Period	% of Time
March - May	80
June - October	90
November - February	75

		No Mechanical Chiller														Total Summary	
Month	Approx. Service Hour				GT41			GT42			ST	Net				No Chiller	
		DB (^{o}C)	F	RH (%)	Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Fuel Consumption (MMBTU/h)	Heat rate (BTU/kWh)	Eff (%)	Total MWh	Fuel Consumption (MMBTU)
Mar-May																	
1:00 AM	72	28.6	83.49	80.5	100.53	11,899	28.68	101.13	11,879	28.73	108.08	309.74	2397.53	7,740	44.09	22,301	172,622
2:00 AM	72	28.4	83.09	82.1	100.68	11,896	28.69	101.28	11,875	28.74	108.09	310.05	2400.39	7,742	44.09	22,324	172,828
3:00 AM	72	28.2	82.75	83.2	100.82	11,892	28.70	101.42	11,872	28.75	108.03	310.27	2403.01	7,745	44.07	22,339	173,017
4:00 AM	72	28.0	82.43	84.4	100.94	11,890	28.70	101.55	11,869	28.76	108.12	310.61	2405.47	7,744	44.07	22,364	173,194
5:00 AM	72	27.9	82.15	85.3	101.05	11,887	28.71	101.66	11,866	28.76	108.15	310.86	2407.48	7,745	44.07	22,382	173,338
6:00 AM	72	27.7	81.93	86.4	101.14	11,885	28.72	101.74	11,864	28.77	108.17	311.05	2409.09	7,745	44.07	22,396	173,455
7:00 AM	72	28.0	82.37	84.9	100.97	11,889	28.71	101.57	11,869	28.76	108.17	310.71	2405.97	7,743	44.08	22,371	173,230
8:00 AM	72	29.4	85.01	77.0	99.92	11,917	28.64	100.52	11,896	28.69	107.98	308.42	2386.54	7,738	44.11	22,206	171,831
9:00 AM	72	30.9	87.66	68.6	99.88	11,946	28.57	99.47	11,925	28.62	107.76	307.10	2379.25	7,748	44.05	22,111	171,306
10:00 AM	72	32.3	90.12	62.6	97.90	11,968	28.52	98.49	11,947	28.57	107.62	304.01	2348.28	7,724	44.18	21,889	169,076
11:00 AM	72	32.8	91.04	61.9	97.53	11,976	28.50	98.12	11,959	28.54	107.58	303.22	2341.39	7,722	44.20	21,832	168,580
12:00 PM	72	33.2	91.77	60.7	97.21	11,967	28.52	97.82	11,966	28.52	107.55	302.58	2333.90	7,713	44.25	21,786	168,041
1:00 PM	72	33.5	92.24	59.6	97.06	11,992	28.46	97.64	11,971	28.51	107.52	302.21	2332.68	7,719	44.22	21,759	167,953
2:00 PM	72	33.5	92.37	59.2	97.00	11,993	28.46	97.58	11,972	28.51	107.50	302.09	2331.64	7,718	44.22	21,751	167,878
3:00 PM	72	33.5	92.30	60.2	97.03	11,993	28.46	97.61	11,973	28.51	107.53	302.17	2332.33	7,719	44.22	21,756	167,928
4:00 PM	72	33.3	91.93	61.2	97.17	11,990	28.47	97.76	11,970	28.51	107.55	302.47	2335.24	7,720	44.21	21,778	168,138
5:00 PM	72	33.0	91.42	62.3	97.38	11,986	28.47	97.96	11,965	28.52	107.44	302.78	2339.23	7,726	44.18	21,800	168,424
6:00 PM	72	32.3	90.19	65.0	97.86	11,974	28.50	98.45	11,953	28.55	107.63	303.94	2348.58	7,727	44.17	21,884	169,098
7:00 PM	72	31.4	88.55	67.7	98.52	11,956	28.55	99.11	11,936	28.59	107.72	305.34	2360.82	7,732	44.14	21,985	169,979
8:00 PM	72	30.8	87.41	69.6	98.97	11,944	28.58	99.57	11,924	28.62	107.76	306.30	2369.35	7,735	44.12	22,053	170,593
9:00 PM	72	30.2	86.41	72.3	99.37	11,933	28.60	99.96	11,912	28.65	107.84	307.17	2376.54	7,737	44.11	22,116	171,111
10:00 PM	72	29.7	85.54	74.5	99.71	11,923	28.63	100.31	11,902	28.68	107.91	307.93	2382.78	7,738	44.11	22,171	171,560
11:00 PM	72	29.4	84.95	76.2	99.95	11,916	28.64	100.55	11,895	28.69	107.97	308.47	2387.02	7,738	44.11	22,210	171,866
12:00 AM	72	29.2	84.54	78.1	100.11	11,911	28.65	100.71	11,891	28.70	108.01	308.83	2389.95	7,739	44.10	22,235	172,077
Sub-Total	**1728**															**529,799**	**4,097,123**

Existing Performance Summary

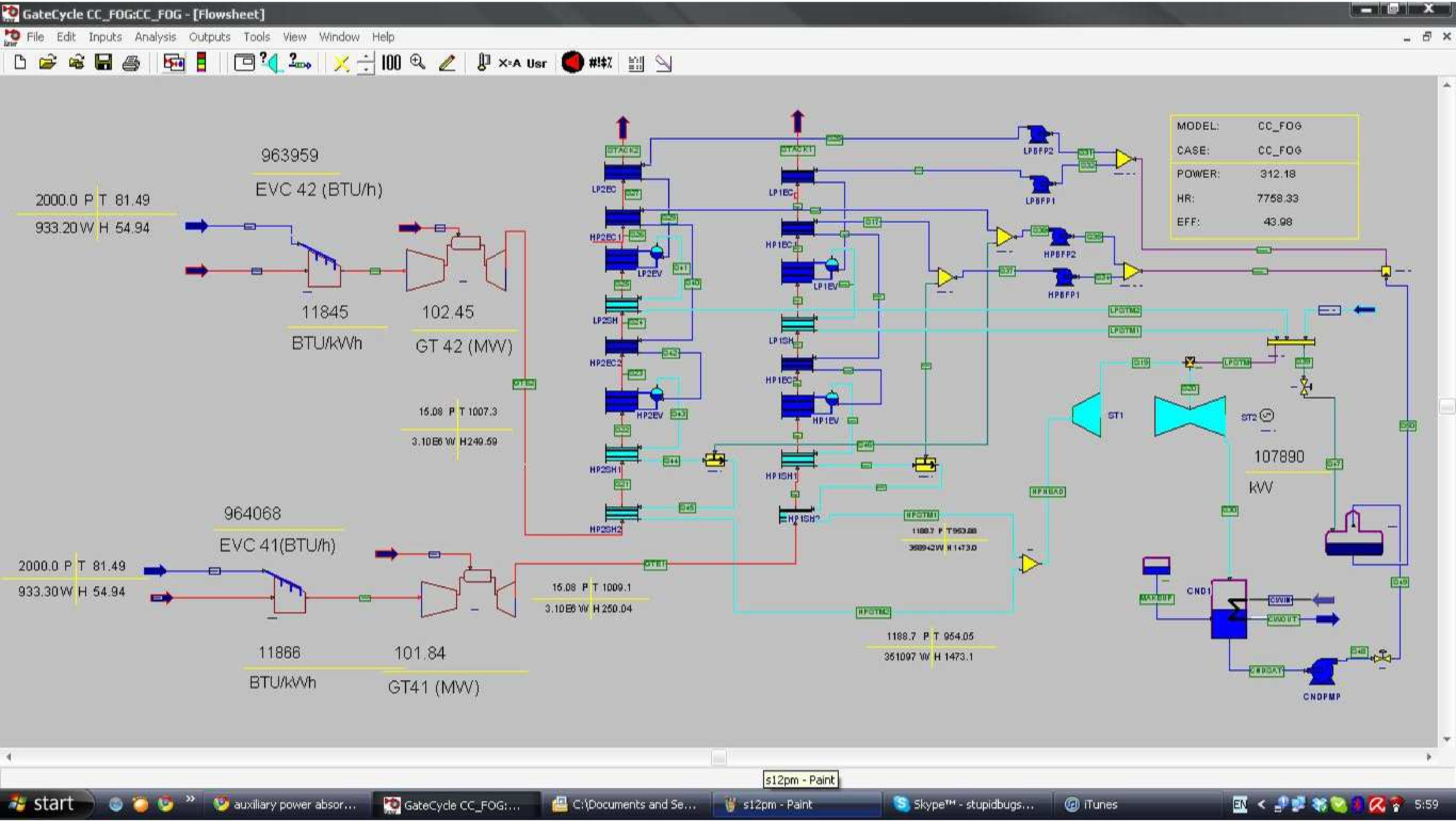
Period	% of Time
March - May	80
June - October	90
November - February	75

		No Mechanical Chiller														Total Summary	
Month	Approx. Service Hour				GT41			GT42			ST	Net				No Chiller	
		DB (^{o}C)	F	RH (%)	Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Fuel Consumption (MMBTU/h)	Heat rate (BTU/kWh)	Eff (%)	Total MWh	Fuel Consumption (MMBTU)
Jun - Oct													0.00				
1:00 AM	135	27.5	81.49	84.9	101.32	11,878	28.73	101.93	11,857	28.78	108.12	311.37	2412.06	7,747	44.06	42,034	325,629
2:00 AM	135	27.3	81.21	85.6	101.43	11,875	28.74	102.04	11,854	28.79	108.17	311.64	2414.06	7,746	44.06	42,072	325,899
3:00 AM	135	27.2	80.92	86.1	101.55	11,872	28.75	102.15	11,851	28.80	108.18	311.88	2416.18	7,747	44.06	42,104	326,184
4:00 AM	135	27.1	80.87	86.4	101.57	11,871	28.75	102.17	11,851	28.80	108.20	311.94	2416.55	7,747	44.06	42,112	326,235
5:00 AM	135	27.4	81.33	86.8	101.38	11,878	28.73	101.99	11,857	28.78	108.18	311.55	2413.49	7,747	44.06	42,059	325,821
6:00 AM	135	27.8	82.11	87.3	101.06	11,888	28.71	101.67	11,868	28.76	108.19	310.92	2408.02	7,745	44.07	41,974	325,083
7:00 AM	135	28.5	83.26	86.7	100.60	11,903	28.67	101.20	11,882	28.72	108.15	309.95	2399.90	7,743	44.08	41,844	323,987
8:00 AM	135	29.4	84.89	81.4	99.96	11,919	28.63	100.50	11,898	28.69	108.06	308.52	2387.12	7,737	44.11	41,650	322,262
9:00 AM	135	30.4	86.72	76.0	99.23	11,939	28.59	99.83	11,919	28.63	107.91	306.96	2374.55	7,736	44.12	41,440	320,564
10:00 AM	135	31.1	87.98	71.0	98.74	11,954	28.55	99.33	11,933	28.60	107.78	305.85	2365.60	7,735	44.13	41,289	319,355
11:00 AM	135	31.6	88.82	67.7	98.41	11,960	28.54	99.00	11,939	28.59	107.71	305.12	2358.90	7,731	44.15	41,191	318,451
12:00 PM	135	31.7	89.11	65.4	98.30	11,960	28.54	98.89	11,939	28.59	107.67	304.86	2356.27	7,729	44.16	41,156	318,096
1:00 PM	135	31.9	89.34	64.3	98.21	11,961	28.53	98.80	11,940	28.58	107.66	304.67	2354.34	7,728	44.17	41,130	317,836
2:00 PM	135	31.7	89.02	65.7	98.34	11,959	28.54	98.92	11,938	28.59	107.69	304.94	2356.93	7,729	44.16	41,167	318,186
3:00 PM	135	31.3	88.42	67.1	98.57	11,954	28.55	99.16	11,933	28.60	107.72	305.45	2361.64	7,732	44.14	41,236	318,822
4:00 PM	135	31.0	87.72	68.2	98.85	11,946	28.57	99.44	11,925	28.62	107.75	306.04	2366.77	7,733	44.13	41,316	319,514
5:00 PM	135	30.4	86.78	70.2	99.23	11,937	28.59	99.82	11,916	28.64	107.79	306.83	2373.92	7,737	44.11	41,423	320,479
6:00 PM	135	29.8	85.63	72.5	99.68	11,923	28.63	100.28	11,902	28.68	107.87	307.83	2382.06	7,738	44.11	41,557	321,579
7:00 PM	135	29.1	84.37	75.2	100.19	11,908	28.66	100.78	11,887	28.71	107.95	308.92	2391.03	7,740	44.10	41,704	322,790
8:00 PM	135	28.7	83.70	77.3	100.45	11,900	28.68	101.05	11,879	28.73	107.85	309.35	2395.73	7,744	44.07	41,762	323,423
9:00 PM	135	28.6	83.41	79.1	100.56	11,897	28.69	101.16	11,876	28.74	108.05	309.77	2397.74	7,740	44.09	41,819	323,695
10:00 PM	135	28.3	82.97	80.9	100.73	11,893	28.70	101.34	11,872	28.75	108.09	310.16	2401.09	7,741	44.09	41,871	324,147
11:00 PM	135	28.0	82.37	82.2	100.97	11,886	28.71	101.58	11,866	28.76	108.11	310.66	2405.48	7,743	44.08	41,940	324,739
12:00 AM	135	27.5	81.58	83.5	101.29	11,878	28.73	101.89	11,857	28.78	108.15	311.33	2411.23	7,745	44.07	42,029	325,516
Sub-Total	**3240**															**999,878**	**7,738,289**

Existing Performance Summary

Period	% of Time
March - May	80
June - October	90
November - February	75

		No Mechanical Chiller															Total Summary	
Month	Approx. Service Hour				GT41			GT42			ST	Net					No Chiller	
		DB (^oC)	F	RH (%)	Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Fuel Consumption (MMBTU/h)	Heat rate (BTU/kWh)	Eff (%)		Total MWh	Fuel Consumption (MMBTU)
Nov - Feb													0.00					
1:00 AM	90	26.0	78.77	74.9	102.44	11,837	28.83	103.05	11,816	28.88	108.07	313.56	2430.22	7,750	44.04		28,220	218,720
2:00 AM	90	25.7	78.18	76.0	102.68	11,830	28.85	103.29	11,810	28.90	108.11	314.08	2434.56	7,751	44.03		28,267	219,110
3:00 AM	90	25.3	77.52	76.9	102.94	11,823	28.87	103.55	11,802	28.92	108.13	314.62	2439.16	7,753	44.02		28,316	219,524
4:00 AM	90	25.0	76.94	78.0	103.17	11,816	28.88	103.78	11,796	28.93	108.15	315.10	2443.25	7,754	44.02		28,359	219,892
5:00 AM	90	24.7	76.48	78.6	103.35	11,811	28.90	103.97	11,790	28.95	108.18	315.50	2446.47	7,754	44.01		28,395	220,183
6:00 AM	90	24.4	75.96	79.3	103.56	11,805	28.91	104.18	11,785	28.96	108.18	315.92	2450.29	7,756	44.00		28,433	220,526
7:00 AM	90	24.3	75.80	79.1	103.62	11,803	28.92	104.24	11,783	28.97	108.18	316.04	2451.29	7,756	44.00		28,443	220,616
8:00 AM	90	25.2	77.38	74.0	103.00	11,820	28.87	103.62	11,799	28.93	108.10	314.72	2440.07	7,753	44.02		28,325	219,607
9:00 AM	90	26.7	80.08	67.0	101.94	11,846	28.81	102.55	11,826	28.86	107.97	312.46	2420.34	7,746	44.06		28,121	217,830
10:00 AM	90	28.0	82.48	61.2	100.99	11,867	28.76	101.59	11,846	28.81	107.87	310.45	2401.88	7,737	44.11		27,941	216,170
11:00 AM	90	29.1	84.38	57.6	100.24	11,896	28.69	100.83	11,865	28.77	107.79	308.86	2388.80	7,734	44.13		27,797	214,992
12:00 PM	90	29.8	85.73	55.1	99.70	11,900	28.68	100.30	11,879	28.73	107.70	307.70	2377.88	7,728	44.16		27,693	214,009
1:00 PM	90	30.6	87.16	53.3	99.13	11,916	28.64	99.72	11,895	28.69	107.61	306.46	2367.39	7,725	44.18		27,582	213,065
2:00 PM	90	31.0	87.88	52.5	98.84	11,924	28.62	99.43	11,903	28.67	107.58	305.85	2362.12	7,723	44.19		27,527	212,591
3:00 PM	90	31.2	88.14	52.5	98.74	11,927	28.62	99.33	11,907	28.66	107.57	305.64	2360.30	7,723	44.20		27,507	212,427
4:00 PM	90	31.2	88.17	53.3	98.72	11,929	28.61	99.31	11,908	28.66	107.57	305.61	2360.26	7,723	44.19		27,505	212,424
5:00 PM	90	30.6	87.14	56.8	99.13	11,920	28.63	99.72	11,899	28.68	107.66	306.50	2368.11	7,726	44.17		27,585	213,130
6:00 PM	90	29.5	85.09	61.9	99.94	11,900	28.68	100.53	11,880	28.73	107.78	308.25	2383.53	7,733	44.14		27,742	214,518
7:00 PM	90	28.5	83.24	65.6	100.67	11,883	28.72	101.27	11,862	28.77	107.86	309.80	2397.53	7,739	44.10		27,882	215,777
8:00 PM	90	28.0	82.46	67.3	100.98	11,876	28.74	101.58	11,855	28.79	107.91	310.47	2403.47	7,741	44.09		27,942	216,312
9:00 PM	90	27.7	81.85	68.7	101.22	11,870	28.75	101.83	11,850	28.80	107.93	310.98	2408.17	7,744	44.07		27,988	216,735
10:00 PM	90	27.3	81.08	70.3	101.53	11,863	28.77	102.13	11,842	28.82	107.96	311.62	2413.87	7,746	44.06		28,046	217,249
11:00 PM	90	26.8	80.29	72.1	101.84	11,854	28.79	102.45	11,834	28.84	108.01	312.30	2419.60	7,748	44.05		28,107	217,764
12:00 AM	90	26.3	79.42	73.9	102.18	11,844	28.82	102.79	11,824	28.87	108.06	313.03	2425.61	7,749	44.05		28,173	218,305
Sub-Total	**2160**																**671,895**	**5,201,476**
Total	**7128**																**2,201,572**	**17,036,888**



MODEL: CC_FOG
CASE: CC_FOG
POWER: 312.18
HR: 7758.33
EFF: 43.98

Evaporative System Performance Summary

	DB (^{o}C)	DB (^{o}C)	%RH
Design	-		90

Period	% of Time
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load 0.08 kW/TR

		Fogging																						Total Summary					
			GT41						GT42						ST	Net							No Fogging		Fogging		Incremental	
Month	Approx. Service Hour	DB (^{o}C)	Output (MW)	Cooling load (TR)	Parasitic Load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Cooling load (TR)	Parasitic Load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Heat rate (BTU/kWh)	Eff (%)	Water Required (m3/h)	Output Increase (MW)	Output Increase (%)	Heat Rate Changed (%)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)
Mar-May																												
1:00 AM	72	28.6	101.53	155	-12	101.52	11877.45	28.74	102.14	155	-12	102.13	11856.44	28.79	107.56	311.21	7765.3	43.95	1.64	1.47	0.47	0.32	22,301	172,622	22,407	173,998	106	1,376
2:00 AM	72	28.4	101.51	128	-10	101.50	11878.19	28.74	102.12	128	-10	102.11	11857.18	28.78	107.69	311.30	7762.2	43.97	1.35	1.24	0.40	0.26	22,324	172,828	22,413	173,979	90	1,151
3:00 AM	72	28.2	101.52	109	-9	101.51	11877.02	28.74	102.13	109	-9	102.12	11856.01	28.79	107.78	311.41	7759.5	43.98	1.15	1.14	0.37	0.19	22,339	173,017	22,422	173,981	82	964
4:00 AM	72	28.0	101.52	89	-7	101.51	11876.83	28.74	102.13	89	-7	102.12	11856.83	28.79	107.86	311.50	7757.7	43.99	0.94	0.89	0.29	0.17	22,364	173,194	22,428	173,988	64	794
5:00 AM	72	27.9	101.54	74	-6	101.53	11876.70	28.74	102.14	74	-6	102.13	11855.69	28.79	107.91	311.58	7756.5	44.00	0.79	0.72	0.23	0.16	22,382	173,338	22,434	174,007	51	668
6:00 AM	72	27.7	101.51	57	-5	101.51	11877.53	28.74	102.11	57	-5	102.11	11856.53	28.79	107.99	311.60	7754.4	44.01	0.60	0.55	0.18	0.12	22,396	173,455	22,435	173,970	40	515
7:00 AM	72	28.0	101.49	81	-6	101.48	11877.76	28.74	102.10	81	-6	102.09	11856.75	28.79	107.87	311.45	7756.9	44.00	0.85	0.74	0.24	0.17	22,371	173,230	22,424	173,944	53	715
8:00 AM	72	29.4	101.33	217	-17	101.31	11884.03	28.72	101.94	217	-17	101.92	11864.02	28.77	107.29	310.52	7771.5	43.92	2.30	2.10	0.68	0.43	22,206	171,831	22,358	173,752	151	1,920
9:00 AM	72	30.9	101.33	377	-30	101.30	11885.53	28.72	101.94	377	-30	101.91	11865.51	28.76	106.60	309.81	7789.3	43.82	4.01	2.71	0.88	0.54	22,111	171,306	22,306	173,752	195	2,445
10:00 AM	72	32.3	101.20	505	-40	101.16	11891.75	28.71	101.80	505	-40	101.76	11870.71	28.75	106.05	308.97	7803.2	43.74	5.38	4.96	1.63	1.02	21,889	169,076	22,245	173,586	357	4,510
11:00 AM	72	32.8	100.96	523	-42	100.92	11898.93	28.70	101.56	523	-42	101.52	11878.90	28.73	105.96	308.39	7804.1	43.73	5.58	5.17	1.71	1.07	21,832	168,580	22,204	173,285	372	4,705
12:00 PM	72	33.2	100.85	552	-44	100.81	11903.21	28.69	101.46	552	-44	101.42	11882.17	28.72	105.83	308.05	7807.0	43.72	5.89	5.47	1.81	1.22	21,786	168,041	22,180	173,157	394	5,116
1:00 PM	72	33.5	100.84	578	-46	100.79	11903.45	28.69	101.44	578	-46	101.39	11883.41	28.72	105.71	307.89	7810.2	43.70	6.16	5.69	1.88	1.18	21,759	167,953	22,168	173,138	409	5,185
2:00 PM	72	33.5	100.85	587	-47	100.80	11903.54	28.69	101.45	587	-47	101.40	11882.50	28.72	105.67	307.88	7810.9	43.70	6.26	5.79	1.92	1.20	21,751	167,878	22,167	173,148	417	5,270
3:00 PM	72	33.5	100.73	565	-45	100.68	11907.34	28.68	101.30	565	-45	101.25	11886.30	28.71	105.76	307.70	7807.6	43.71	6.03	5.53	1.83	1.15	21,756	167,928	22,155	172,975	398	5,048
4:00 PM	72	33.3	100.73	543	-43	100.69	11907.13	28.68	101.33	543	-43	101.29	11886.09	28.71	105.86	307.83	7805.5	43.73	5.78	5.36	1.77	1.10	21,778	168,138	22,164	173,001	386	4,863
5:00 PM	72	33.0	100.76	517	-41	100.72	11905.88	28.68	101.36	517	-41	101.32	11884.85	28.72	105.97	308.01	7802.8	43.74	5.51	5.23	1.73	0.99	21,800	168,424	22,176	173,038	377	4,613
6:00 PM	72	32.3	100.85	457	-37	100.81	11902.31	28.69	101.45	457	-37	101.41	11881.28	28.73	106.24	308.46	7796.1	43.78	4.86	4.53	1.49	0.89	21,884	169,098	22,209	173,148	326	4,050
7:00 PM	72	31.4	101.11	398	-32	101.08	11892.74	28.71	101.72	398	-32	101.69	11872.71	28.75	106.51	309.28	7790.5	43.81	4.22	3.93	1.29	0.76	21,985	169,979	22,268	173,478	283	3,498
8:00 PM	72	30.8	101.30	358	-29	101.27	11886.36	28.72	101.91	358	-29	101.88	11866.33	28.76	106.71	309.86	7786.3	43.83	3.79	3.57	1.16	0.66	22,053	170,593	22,310	173,715	257	3,122
9:00 PM	72	30.2	101.35	304	-24	101.33	11884.85	28.72	101.96	304	-24	101.94	11863.83	28.77	106.92	310.18	7781.3	43.86	3.23	3.01	0.98	0.57	22,116	171,111	22,333	173,778	217	2,667
10:00 PM	72	29.7	101.42	263	-21	101.40	11881.46	28.73	102.03	263	-21	102.01	11861.44	28.77	107.11	310.51	7776.6	43.89	2.78	2.58	0.84	0.50	22,171	171,560	22,357	173,861	186	2,301
11:00 PM	72	29.4	101.45	231	-18	101.43	11880.16	28.73	102.06	231	-18	102.04	11860.15	28.78	107.24	310.71	7773.3	43.91	2.45	2.25	0.73	0.45	22,210	171,866	22,371	173,898	162	2,032
12:00 AM	72	29.2	101.39	198	-16	101.37	11881.85	28.73	102.00	198	-16	101.98	11861.84	28.77	107.38	310.74	7769.3	43.93	2.09	1.92	0.62	0.39	22,235	172,077	22,373	173,825	138	1,748
Sub-Total	**1728**																						**529,799**	**4,097,123**	**535,309**	**4,166,402**	**5,510**	**69,279**

Evaporative System Performance Summary

	DB (°C)	DB (°C)	%RH
Design	-		90

Period	% of Time
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load 0.08 kW/TR

		Fogging																					Total Summary					
			GT41						GT42						ST	Net							No Fogging		Fogging		Incremental	
Month	**Approx. Service Hour**	**DB (°C)**	**Output (MW)**	**Cooling load (TR)**	**Parasitic Load (kW)**	**Net Output (MW)**	**Heat Rate (BTU/kWh)**	**EFF (%)**	**Output (MW)**	**Cooling load (TR)**	**Parasitic Load (kW)**	**Net Output (MW)**	**Heat Rate (BTU/kWh)**	**EFF (%)**	**MW**	**Output (MW)**	**Heat rate (BTU/kWh)**	**Eff (%)**	**Water Required (m3/h)**	**Output Increase (MW)**	**Output Increase (%)**	**Heat Rate Changed (%)**	**Total MWh**	**Fuel Consumption (MMBTU)**	**Total MWh**	**Fuel Consumption (MMBTU)**	**Total MWh**	**Fuel Consumption (MMBTU)**
Jun - Oct																											0	0
1:00 AM	135	27.5	101.84	80	-6	101.83	11866.75	28.76	102.45	80	-6	102.44	11845.74	28.81	107.89	312.17	7758.5	43.99	0.85	0.80	0.26	0.15	42,034	325,629	42,143	326,964	108	1,335
2:00 AM	135	27.3	101.88	69	-6	101.87	11865.64	28.77	102.49	69	-6	102.48	11844.64	28.81	107.94	312.30	7757.5	44.00	0.73	0.66	0.21	0.14	42,072	325,899	42,161	327,064	89	1,166
3:00 AM	135	27.2	101.94	61	-5	101.94	11863.57	28.77	102.55	61	-5	102.55	11842.56	28.82	107.98	312.46	7756.8	44.00	0.64	0.58	0.19	0.13	42,104	326,184	42,183	327,201	78	1,017
4:00 AM	135	27.1	101.93	56	-4	101.93	11863.52	28.77	102.54	56	-4	102.54	11843.52	28.82	108.05	312.51	7755.3	44.01	0.59	0.57	0.18	0.11	42,112	326,235	42,188	327,183	77	948
5:00 AM	135	27.4	101.71	50	-4	101.71	11870.47	28.75	102.31	50	-4	102.31	11850.46	28.80	108.02	312.03	7754.6	44.01	0.53	0.48	0.15	0.10	42,059	325,821	42,124	326,656	65	835
6:00 AM	135	27.8	101.34	42	-3	101.34	11882.40	28.72	101.95	42	-3	101.95	11861.39	28.77	108.04	311.33	7751.8	44.03	0.45	0.41	0.13	0.09	41,974	325,083	42,029	325,802	56	720
7:00 AM	135	28.5	100.94	52	-4	100.94	11895.49	28.69	101.55	52	-4	101.55	11874.49	28.74	107.98	310.46	7751.3	44.03	0.56	0.51	0.16	0.11	41,844	323,987	41,912	324,876	69	889
8:00 AM	135	29.4	100.87	140	-11	100.86	11898.32	28.69	101.47	140	-11	101.46	11878.31	28.73	107.60	309.92	7760.8	43.98	1.48	1.40	0.45	0.30	41,650	322,262	41,839	324,703	189	2,441
9:00 AM	135	30.4	100.79	238	-19	100.77	11902.25	28.68	101.39	155	-12	101.38	11880.45	28.73	107.17	309.32	7771.2	43.92	2.53	2.36	0.77	0.46	41,440	320,564	41,758	324,515	319	3,951
10:00 AM	135	31.1	100.91	333	-27	100.88	11899.14	28.69	101.52	333	-27	101.49	11878.11	28.73	106.78	309.15	7782.5	43.85	3.54	3.30	1.08	0.62	41,289	319,355	41,735	324,807	446	5,451
11:00 AM	135	31.6	101.01	398	-32	100.98	11896.75	28.70	101.62	398	-32	101.59	11875.72	28.74	106.50	309.07	7790.4	43.81	4.24	3.95	1.29	0.77	41,191	318,451	41,724	325,046	533	6,594
12:00 PM	135	31.7	101.20	444	-36	101.16	11890.17	28.71	101.81	444	-36	101.77	11870.14	28.75	106.32	309.26	7795.8	43.78	4.73	4.40	1.44	0.86	41,156	318,096	41,750	325,477	594	7,381
1:00 PM	135	31.9	101.26	467	-37	101.22	11889.38	28.72	101.86	468	-37	101.82	11868.36	28.76	106.22	309.26	7799.0	43.76	4.97	4.60	1.51	0.92	41,130	317,836	41,750	325,612	620	7,777
2:00 PM	135	31.7	101.19	438	-35	101.15	11891.12	28.71	101.80	438	-35	101.76	11870.09	28.75	106.34	309.26	7795.4	43.78	4.66	4.32	1.42	0.86	41,167	318,186	41,750	325,459	583	7,273
3:00 PM	135	31.3	101.20	408	-33	101.17	11888.84	28.72	101.84	408	-33	101.81	11868.81	28.76	106.47	309.44	7791.7	43.80	4.34	3.99	1.31	0.78	41,236	318,822	41,775	325,498	539	6,676
4:00 PM	135	31.0	101.36	385	-31	101.33	11884.61	28.73	101.97	385	-31	101.94	11864.58	28.77	106.58	309.85	7790.1	43.81	4.09	3.80	1.24	0.73	41,316	319,514	41,829	325,853	513	6,339
5:00 PM	135	30.4	101.47	344	-28	101.44	11881.22	28.73	102.07	344	-28	102.04	11860.20	28.78	106.76	310.24	7785.8	43.84	3.65	3.41	1.11	0.63	41,423	320,479	41,883	326,093	460	5,614
6:00 PM	135	29.8	101.62	298	-24	101.60	11875.79	28.75	102.23	298	-24	102.21	11854.77	28.79	106.96	310.76	7781.3	43.86	3.16	2.93	0.95	0.56	41,557	321,579	41,953	326,452	396	4,873
7:00 PM	135	29.1	101.79	248	-20	101.77	11870.31	28.76	102.40	248	-20	102.38	11849.29	28.80	107.12	311.27	7778.4	43.88	2.62	2.35	0.76	0.50	41,704	322,790	42,021	326,859	317	4,069
8:00 PM	135	28.7	101.81	209	-17	101.79	11868.95	28.76	102.42	209	-17	102.40	11847.94	28.81	107.31	311.51	7773.3	43.91	2.22	2.16	0.70	0.37	41,762	323,423	42,054	326,895	291	3,472
9:00 PM	135	28.6	101.72	178	-14	101.71	11871.67	28.75	102.33	178	-14	102.32	11850.65	28.80	107.73	311.75	7762.3	43.97	1.88	1.99	0.64	0.28	41,819	323,695	42,087	326,690	268	2,995
10:00 PM	135	28.3	101.69	148	-12	101.68	11872.38	28.75	102.30	148	-12	102.29	11851.37	28.80	107.61	311.58	7765.0	43.95	1.56	1.42	0.46	0.30	41,871	324,147	42,063	326,621	192	2,474
11:00 PM	135	28.0	101.78	125	-10	101.77	11869.17	28.76	102.39	125	-10	102.38	11848.16	28.81	107.70	311.85	7763.1	43.96	1.32	1.19	0.38	0.26	41,940	324,739	42,100	326,827	161	2,087
12:00 AM	135	27.5	101.95	103	-8	101.94	11862.95	28.77	102.56	103	-8	102.55	11842.95	28.82	107.81	312.30	7761.3	43.97	1.09	0.98	0.31	0.21	42,029	325,516	42,161	327,219	132	1,703
Sub-Total	**3240**																						**999,878**	**7,738,289**	**1,006,973**	**7,826,370**	**7,095**	**88,081**

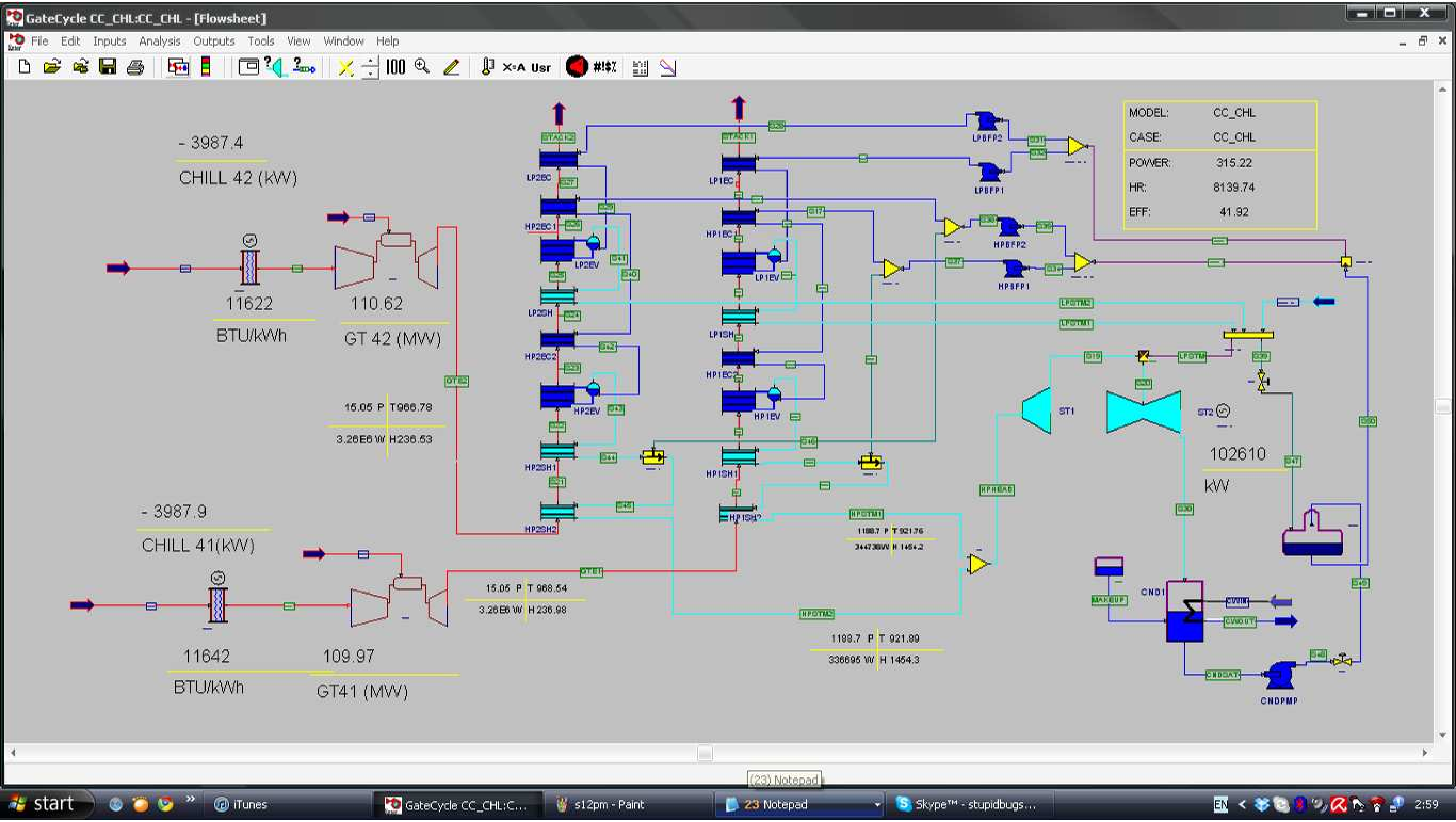
Evaporative System Performance Summary

	DB (°C)	DB (°C)	%RH
Design	-		90

Period	% of Time
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load 0.08 kW/TR

		Fogging																					Total Summary					
Month	**Approx. Service Hour**		**GT41**						**GT42**						**ST**	**Net**							**No Fogging**		**Fogging**		**Incremental**	
		DB (°C)	**Output (MW)**	**Cooling load (TR)**	**Parasitic Load (kW)**	**Net Output (MW)**	**Heat Rate (BTU/kWh)**	**EFF (%)**	**Output (MW)**	**Cooling load (TR)**	**Parasitic Load (kW)**	**Net Output (MW)**	**Heat Rate (BTU/kWh)**	**EFF (%)**	**MW**	**Output (MW)**	**Heat rate (BTU/kWh)**	**Eff (%)**	**Water Required (m3/h)**	**Output Increase (MW)**	**Output Increase (%)**	**Heat Rate Changed (%)**	**Total MWh**	**Fuel Consumption (MMBTU)**	**Total MWh**	**Fuel Consumption (MMBTU)**	**Total MWh**	**Fuel Consumption (MMBTU)**
Nov - Feb																											0	0
1:00 AM	90	26.0	103.96	239	-19	103.94	11803.17	28.92	104.59	239	-19	104.57	11782.16	28.97	107.29	315.80	7786.2	43.83	2.52	2.24	0.72	0.46	28,220	218,720	28,422	221,301	202	2,581
2:00 AM	90	25.7	104.07	220	-18	104.05	11799.00	28.93	104.69	220	-18	104.67	11778.98	28.98	107.38	316.11	7784.2	43.85	2.31	2.03	0.65	0.42	28,267	219,110	28,450	221,458	183	2,348
3:00 AM	90	25.3	104.23	203	-16	104.21	11794.84	28.94	104.85	203	-16	104.83	11773.83	28.99	107.46	316.50	7783.4	43.85	2.14	1.89	0.60	0.40	28,316	219,524	28,485	221,713	170	2,189
4:00 AM	90	25.0	104.34	185	-15	104.33	11791.67	28.95	104.96	185	-15	104.95	11770.66	29.00	107.54	316.81	7782.1	43.86	1.94	1.71	0.54	0.36	28,359	219,892	28,513	221,890	154	1,998
5:00 AM	90	24.7	104.45	174	-14	104.44	11787.57	28.96	105.08	174	-14	105.07	11767.56	29.00	107.59	317.09	7781.4	43.86	1.83	1.59	0.50	0.35	28,395	220,183	28,538	222,068	143	1,885
6:00 AM	90	24.4	104.58	163	-13	104.57	11784.46	28.97	105.21	163	-13	105.20	11763.45	29.01	107.64	317.41	7781.0	43.86	1.71	1.49	0.47	0.32	28,433	220,526	28,567	222,277	134	1,751
7:00 AM	90	24.3	104.66	165	-13	104.65	11781.49	28.97	105.29	165	-13	105.28	11761.47	29.02	107.64	317.56	7781.5	43.86	1.74	1.52	0.48	0.32	28,443	220,616	28,580	222,399	137	1,784
8:00 AM	90	25.2	104.59	251	-20	104.57	11785.26	28.97	105.21	251	-20	105.19	11764.24	29.01	107.28	317.04	7790.3	43.81	1.45	2.32	0.74	0.48	28,325	219,607	28,534	222,288	209	2,681
9:00 AM	90	26.7	104.34	379	-30	104.31	11793.43	28.95	104.97	379	-30	104.94	11772.40	28.99	106.74	315.99	7802.7	43.74	4.00	3.53	1.13	0.73	28,121	217,830	28,439	221,900	318	4,070
10:00 AM	90	28.0	104.15	497	-40	104.11	11799.50	28.94	104.78	497	-40	104.74	11779.47	28.97	106.22	315.07	7814.8	43.67	5.25	4.62	1.49	1.01	27,941	216,170	28,357	221,601	416	5,432
11:00 AM	90	29.1	103.92	578	-46	103.87	11807.25	28.92	104.55	578	-46	104.50	11786.21	28.96	105.89	314.27	7821.8	43.63	6.11	5.41	1.75	1.13	27,797	214,992	28,284	221,235	487	6,243
12:00 PM	90	29.8	103.77	637	-51	103.72	11811.80	28.91	104.39	637	-51	104.34	11791.75	28.94	105.64	313.70	7827.5	43.60	6.75	5.99	1.95	1.29	27,693	214,009	28,233	220,990	539	6,981
1:00 PM	90	30.6	103.52	683	-55	103.47	11820.24	28.89	104.14	683	-55	104.09	11799.19	28.93	105.43	312.98	7831.6	43.58	7.26	6.52	2.13	1.38	27,582	213,065	28,168	220,600	587	7,535
2:00 PM	90	31.0	103.38	706	-56	103.32	11824.46	28.88	104.00	706	-56	103.94	11804.41	28.91	105.33	312.60	7833.5	43.57	7.50	6.74	2.20	1.43	27,527	212,591	28,134	220,386	607	7,796
3:00 PM	90	31.2	103.29	708	-57	103.23	11827.48	28.87	103.91	708	-57	103.85	11806.43	28.91	105.32	312.40	7833.3	43.57	7.52	6.77	2.21	1.43	27,507	212,427	28,116	220,242	609	7,815
4:00 PM	90	31.2	103.17	690	-55	103.11	11831.33	28.86	103.78	690	-55	103.72	11810.28	28.90	105.38	312.22	7831.0	43.58	7.34	6.62	2.17	1.40	27,505	212,424	28,100	220,050	595	7,627
5:00 PM	90	30.6	103.05	610	-49	103.00	11833.60	28.86	103.67	609	-49	103.62	11813.55	28.89	105.72	312.34	7821.7	43.64	6.93	5.84	1.90	1.24	27,585	213,130	28,110	219,871	525	6,741
6:00 PM	90	29.5	103.12	496	-40	103.08	11830.55	28.86	103.74	496	-40	103.70	11809.52	28.90	106.20	312.98	7809.4	43.70	5.26	4.73	1.53	0.99	27,742	214,518	28,168	219,973	426	5,455
7:00 PM	90	28.5	103.40	418	-33	103.37	11822.82	28.88	103.96	418	-33	103.93	11802.79	28.92	106.54	313.83	7802.6	43.74	4.41	4.04	1.30	0.82	27,882	215,777	28,245	220,384	363	4,606
8:00 PM	90	28.0	103.43	383	-31	103.40	11820.50	28.88	104.05	383	-31	104.02	11799.47	28.93	106.69	314.10	7798.7	43.76	4.05	3.64	1.17	0.74	27,942	216,312	28,269	220,465	327	4,152
9:00 PM	90	27.7	103.49	355	-28	103.46	11818.24	28.89	104.11	355	-28	104.08	11797.22	28.93	106.80	314.34	7796.0	43.78	3.75	3.37	1.08	0.67	27,988	216,735	28,291	220,555	303	3,820
10:00 PM	90	27.3	103.60	324	-26	103.57	11814.96	28.89	104.22	324	-26	104.19	11793.93	28.94	106.93	314.70	7793.4	43.79	3.42	3.08	0.99	0.61	28,046	217,249	28,323	220,732	277	3,484
11:00 PM	90	26.8	103.69	291	-23	103.67	11811.65	28.90	104.31	291	-23	104.29	11790.63	28.95	107.08	315.03	7790.0	43.81	3.07	2.73	0.87	0.55	28,107	217,764	28,353	220,867	246	3,103
12:00 AM	90	26.3	103.82	258	-21	103.80	11807.34	28.91	104.45	258	-21	104.43	11786.32	28.96	107.22	315.45	7787.2	43.83	2.72	2.42	0.77	0.49	28,173	218,305	28,390	221,079	218	2,774
Sub-Total	**2160**																						**671,895**	**5,201,476**	**680,069**	**5,306,326**	**8,174**	**104,850**
Total	**7128**																						**2,201,572**	**17,036,888**	**2,222,351**	**17,299,098**	**20,779**	**262,210**



MODEL:	CC_CHL
CASE:	CC_CHL
POWER:	315.22
HR:	8139.74
EFF:	41.92

Mechanical Chiller System Performance Summary

	DB (^{o}C)	DB (^{o}C)	%RH
Design criteria	15.0		100

Period	% of
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load from Mechanical Chiller (Inc. pump and cooling tower) 1 kW/TR

		No	Mechanical Chiller																				Total Summary					
				GT41						GT42						ST	Net						No Chiller		Mechanical Chiller		Incremental	
Month	Approx. Service Hour	DB (^{o}C)	DB (^{o}C)	Output (MW)	Cooling Load (TR)	Parasitic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Cooling Load (TR)	Parasitic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Heat rate (BTU/kWh)	Eff (%)	Output Increase (MW)	Output Increase (%)	Heat Rate Changed (%)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)
Mar-May																												
1:00 AM	72	28.6	15	109.97	4,184.5	-4,184.5	105.79	12,103	28.20	110.62	4,184.0	-4,184.0	106.44	12,079	28.26	102.11	314.33	8,163	41.81	4.59	1.48	5.46	22,301	172,622	22,632	184,745	331	12,122
2:00 AM	72	28.4	15	109.97	4,197.8	-4,197.8	105.77	12,104	28.20	110.62	4,197.3	-4,197.3	106.42	12,080	28.25	102.21	314.41	8,161	41.82	4.35	1.40	5.42	22,324	172,828	22,637	184,745	313	11,917
3:00 AM	72	28.2	15	109.97	4,189.1	-4,189.1	105.78	12,103	28.20	110.62	4,188.6	-4,188.6	106.43	12,079	28.25	102.30	314.51	8,158	41.83	4.24	1.37	5.34	22,339	173,017	22,645	184,745	305	11,728
4:00 AM	72	28.0	15	109.97	4,191.6	-4,191.6	105.78	12,103	28.20	110.62	4,191.2	-4,191.2	106.43	12,080	28.25	102.38	314.58	8,156	41.84	3.98	1.28	5.32	22,364	173,194	22,650	184,745	286	11,550
5:00 AM	72	27.9	15	109.97	4,182.3	-4,182.3	105.79	12,102	28.20	110.62	4,181.8	-4,181.8	106.44	12,079	28.26	102.45	314.67	8,154	41.86	3.81	1.23	5.29	22,382	173,338	22,656	184,745	274	11,406
6:00 AM	72	27.7	15	109.97	4,201.6	-4,201.6	105.77	12,104	28.20	110.62	4,201.1	-4,201.1	106.42	12,081	28.25	102.50	314.69	8,154	41.86	3.64	1.17	5.28	22,396	173,455	22,658	184,745	262	11,290
7:00 AM	72	28.0	15	109.97	4,211.4	-4,211.4	105.76	12,106	28.19	110.62	4,210.9	-4,210.9	106.41	12,082	28.25	102.39	314.56	8,157	41.84	3.85	1.24	5.34	22,371	173,230	22,648	184,745	277	11,515
8:00 AM	72	29.4	15	109.97	4,309.0	-4,309.0	105.66	12,117	28.17	110.62	4,308.5	-4,308.5	106.31	12,093	28.22	101.73	313.71	8,179	41.73	5.29	1.71	5.70	22,206	171,831	22,587	184,745	381	12,913
9:00 AM	72	30.9	15	109.97	4,303.2	-4,303.2	105.67	12,116	28.17	110.62	4,302.7	-4,302.7	106.32	12,092	28.22	101.07	313.06	8,196	41.64	5.96	1.94	5.79	22,111	171,306	22,540	184,745	429	13,438
10:00 AM	72	32.3	15	109.97	4,384.9	-4,384.9	105.59	12,125	28.15	110.62	4,384.4	-4,384.4	106.24	12,102	28.20	100.46	312.28	8,217	41.54	8.27	2.72	6.37	21,889	169,076	22,484	184,745	596	15,668
11:00 AM	72	32.8	15	109.97	4,543.3	-4,543.3	105.43	12,144	28.11	110.62	4,542.8	-4,542.8	106.08	12,120	28.16	100.23	311.73	8,231	41.46	8.51	2.81	6.60	21,832	168,580	22,445	184,745	613	16,165
12:00 PM	72	33.2	15	109.97	4,608.7	-4,608.7	105.36	12,151	28.09	110.62	4,608.1	-4,608.1	106.01	12,127	28.14	100.05	311.42	8,239	41.42	8.84	2.92	6.82	21,786	168,041	22,422	184,745	636	16,704
1:00 PM	72	33.5	15	109.97	4,618.8	-4,618.8	105.35	12,152	28.08	110.62	4,618.3	-4,618.3	106.00	12,128	28.14	99.93	311.28	8,243	41.40	9.07	3.00	6.79	21,759	167,953	22,412	184,745	653	16,791
2:00 PM	72	33.5	15	109.97	4,612.2	-4,612.2	105.36	12,152	28.09	110.62	4,611.7	-4,611.7	106.01	12,128	28.14	99.90	311.26	8,243	41.40	9.17	3.04	6.80	21,751	167,878	22,411	184,745	660	16,866
3:00 PM	72	33.5	15	109.97	4,690.4	-4,690.4	105.28	12,161	28.07	110.62	4,689.9	-4,689.9	105.93	12,137	28.12	99.91	311.12	8,247	41.38	8.95	2.96	6.85	21,756	167,928	22,401	184,745	645	16,817
4:00 PM	72	33.3	15	109.97	4,694.5	-4,694.5	105.28	12,161	28.06	110.62	4,694.0	-4,694.0	105.93	12,137	28.12	100.01	311.21	8,245	41.40	8.73	2.89	6.79	21,778	168,138	22,407	184,745	629	16,607
5:00 PM	72	33.0	15	109.97	4,672.9	-4,672.9	105.30	12,159	28.07	110.62	4,672.3	-4,672.3	105.95	12,135	28.13	100.13	311.38	8,240	41.42	8.60	2.84	6.66	21,800	168,424	22,419	184,745	619	16,320
6:00 PM	72	32.3	15	109.97	4,615.4	-4,615.4	105.35	12,152	28.09	110.62	4,614.8	-4,614.8	106.01	12,128	28.14	100.44	311.80	8,229	41.47	7.86	2.59	6.50	21,884	169,098	22,450	184,745	566	15,646
7:00 PM	72	31.4	15	109.97	4,446.1	-4,446.1	105.52	12,133	28.13	110.62	4,445.6	-4,445.6	106.17	12,109	28.19	100.85	312.55	8,210	41.57	7.21	2.36	6.18	21,985	169,979	22,504	184,745	519	14,765
8:00 PM	72	30.8	15	109.97	4,324.0	-4,324.0	105.65	12,118	28.16	110.62	4,323.5	-4,323.5	106.30	12,095	28.22	101.14	313.08	8,196	41.64	6.78	2.21	5.95	22,053	170,593	22,542	184,745	488	14,152
9:00 PM	72	30.2	15	109.97	4,294.7	-4,294.7	105.68	12,115	28.17	110.62	4,294.2	-4,294.2	106.33	12,091	28.23	101.39	313.39	8,188	41.68	6.21	2.02	5.83	22,116	171,111	22,564	184,745	447	13,634
10:00 PM	72	29.7	15	109.97	4,250.6	-4,250.6	105.72	12,110	28.18	110.62	4,250.1	-4,250.1	106.37	12,086	28.24	101.60	313.69	8,180	41.73	5.76	1.87	5.71	22,171	171,560	22,586	184,745	415	13,184
11:00 PM	72	29.4	15	109.97	4,233.5	-4,233.5	105.74	12,108	28.19	110.62	4,233.0	-4,233.0	106.39	12,084	28.24	101.75	313.87	8,175	41.75	5.41	1.75	5.64	22,210	171,866	22,599	184,745	389	12,879
12:00 AM	72	29.2	15	109.97	4,273.2	-4,273.2	105.70	12,113	28.18	110.62	4,272.7	-4,272.7	106.35	12,089	28.23	101.85	313.90	8,174	41.75	5.07	1.64	5.63	22,235	172,077	22,600	184,745	365	12,668
Sub-Total	**1728**																						**529,799**	**4,097,123**	**540,898**	**4,433,869**	**11,100**	**336,746**

Mechanical Chiller System Performance Summary

	DB (°C)	DB (°C)	%RH
Design criteria	15.0		100

Period	% of
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load from Mechanical Chiller (Inc. pump and cooling tower) 1 kW/TR

		No	Mechanical Chiller																				Total Summary					
				GT41						GT42						ST	Net						No Chiller		Mechanical Chiller		Incremental	
Month	Approx. Service Hour	DB (°C)	DB (°C)	Output (MW)	Cooling Load (TR)	Parasitic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Cooling Load (TR)	Parasitic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Heat rate (BTU/kWh)	Eff (%)	Output Increase (MW)	Output Increase (%)	Heat Rate Changed (%)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)
Jun - Oct																											0	0
1:00 AM	135	27.5	15	109.97	3,987.9	-3,987.9	105.98	12,080	28.25	110.62	3,987.4	-3,987.4	106.63	12,057	28.31	102.61	315.22	8,140	41.93	3.86	1.24	5.08	42,034	325,629	42,555	346,396	521	20,768
2:00 AM	135	27.3	15	109.97	3,964.6	-3,964.6	106.01	12,077	28.26	110.62	3,964.2	-3,964.2	106.66	12,054	28.31	102.68	315.34	8,137	41.94	3.70	1.19	5.04	42,072	325,899	42,571	346,396	500	20,497
3:00 AM	135	27.2	15	109.97	3,925.4	-3,925.4	106.04	12,073	28.27	110.62	3,924.9	-3,924.9	106.70	12,050	28.32	102.75	315.49	8,133	41.96	3.61	1.16	4.98	42,104	326,184	42,591	346,396	487	20,212
4:00 AM	135	27.1	15	109.97	3,932.5	-3,932.5	106.04	12,074	28.27	110.62	3,932.1	-3,932.1	106.69	12,050	28.32	102.77	315.49	8,133	41.96	3.55	1.14	4.98	42,112	326,235	42,591	346,396	479	20,161
5:00 AM	135	27.4	15	109.97	4,075.2	-4,075.2	105.89	12,090	28.23	110.62	4,074.7	-4,074.7	106.55	12,066	28.28	102.65	315.09	8,143	41.91	3.54	1.14	5.12	42,059	325,821	42,537	346,396	478	20,575
6:00 AM	135	27.8	15	109.97	4,310.0	-4,310.0	105.66	12,117	28.17	110.62	4,309.6	-4,309.6	106.31	12,093	28.22	102.46	314.43	8,161	41.82	3.51	1.13	5.37	41,974	325,083	42,448	346,396	474	21,313
7:00 AM	135	28.5	15	109.97	4,570.5	-4,570.5	105.40	12,147	28.10	110.62	4,570.0	-4,570.0	106.05	12,123	28.15	102.17	313.62	8,182	41.72	3.67	1.18	5.67	41,844	323,987	42,339	346,396	495	22,409
8:00 AM	135	29.4	15	109.97	4,610.9	-4,610.9	105.36	12,151	28.09	110.62	4,610.4	-4,610.4	106.01	12,127	28.14	101.76	313.13	8,194	41.65	4.62	1.50	5.90	41,650	322,262	42,273	346,396	623	24,134
9:00 AM	135	30.4	15	109.97	4,667.8	-4,667.8	105.30	12,158	28.07	110.62	4,667.2	-4,667.2	105.95	12,134	28.13	101.31	312.56	8,209	41.58	5.60	1.82	6.12	41,440	320,564	42,196	346,396	756	25,832
10:00 AM	135	31.1	15	109.97	4,581.3	-4,581.3	105.39	12,148	28.09	110.62	4,580.8	-4,580.8	106.04	12,124	28.15	100.99	312.42	8,213	41.56	6.57	2.15	6.18	41,289	319,355	42,177	346,396	887	27,041
11:00 AM	135	31.6	15	109.97	4,512.8	-4,512.8	105.46	12,140	28.11	110.62	4,512.2	-4,512.2	106.11	12,116	28.17	100.78	312.35	8,215	41.55	7.23	2.37	6.26	41,191	318,451	42,167	346,396	976	27,945
12:00 PM	135	31.7	15	109.97	4,386.4	-4,386.4	105.58	12,126	28.15	110.62	4,385.9	-4,385.9	106.23	12,102	28.20	100.72	312.53	8,210	41.57	7.67	2.52	6.22	41,156	318,096	42,192	346,396	1,036	28,300
1:00 PM	135	31.9	15	109.97	4,346.9	-4,346.9	105.62	12,121	28.16	110.62	4,346.4	-4,346.4	106.27	12,097	28.21	100.65	312.55	8,210	41.57	7.88	2.59	6.24	41,130	317,836	42,194	346,396	1,064	28,560
2:00 PM	135	31.7	15	109.97	4,390.9	-4,390.9	105.58	12,126	28.15	110.62	4,390.4	-4,390.4	106.23	12,102	28.20	100.73	312.54	8,210	41.57	7.60	2.49	6.22	41,167	318,186	42,193	346,396	1,026	28,210
3:00 PM	135	31.3	15	109.97	4,363.4	-4,363.4	105.61	12,123	28.15	110.62	4,362.9	-4,362.9	106.26	12,099	28.21	100.88	312.75	8,204	41.60	7.30	2.39	6.11	41,236	318,822	42,221	346,396	985	27,574
4:00 PM	135	31.0	15	109.97	4,285.2	-4,285.2	105.68	12,114	28.17	110.62	4,284.7	-4,284.7	106.34	12,090	28.23	101.06	313.08	8,196	41.64	7.04	2.30	5.98	41,316	319,514	42,266	346,396	950	26,882
5:00 PM	135	30.4	15	109.97	4,218.9	-4,218.9	105.75	12,106	28.19	110.62	4,218.4	-4,218.4	106.40	12,083	28.25	101.29	313.45	8,186	41.69	6.61	2.15	5.81	41,423	320,479	42,315	346,396	893	25,917
6:00 PM	135	29.8	15	109.97	4,119.0	-4,119.0	105.85	12,095	28.22	110.62	4,118.6	-4,118.6	106.50	12,071	28.27	101.58	313.93	8,173	41.76	6.10	1.98	5.62	41,557	321,579	42,381	346,396	824	24,817
7:00 PM	135	29.1	15	109.97	4,016.2	-4,016.2	105.95	12,083	28.25	110.62	4,015.8	-4,015.8	106.60	12,060	28.30	101.89	314.45	8,160	41.83	5.53	1.79	5.43	41,704	322,790	42,451	346,396	747	23,606
8:00 PM	135	28.7	15	109.97	4,005.6	-4,005.6	105.96	12,082	28.25	110.62	4,005.1	-4,005.1	106.61	12,059	28.30	102.06	314.64	8,155	41.85	5.29	1.71	5.30	41,762	323,423	42,476	346,396	714	22,973
9:00 PM	135	28.6	15	109.97	4,063.9	-4,063.9	105.91	12,089	28.23	110.62	4,063.4	-4,063.4	106.56	12,065	28.29	102.13	314.59	8,156	41.85	4.83	1.56	5.37	41,819	323,695	42,470	346,396	651	22,701
10:00 PM	135	28.3	15	109.97	4,082.5	-4,082.5	105.89	12,091	28.23	110.62	4,082.1	-4,082.1	106.54	12,067	28.28	102.24	314.67	8,154	41.86	4.51	1.45	5.33	41,871	324,147	42,480	346,396	609	22,249
11:00 PM	135	28.0	15	109.97	4,024.0	-4,024.0	105.95	12,084	28.24	110.62	4,023.5	-4,023.5	106.60	12,061	28.30	102.39	314.93	8,147	41.89	4.27	1.37	5.22	41,940	324,739	42,516	346,396	577	21,657
12:00 AM	135	27.5	15	109.97	3,916.0	-3,916.0	106.05	12,072	28.27	110.62	3,915.5	-3,915.5	106.70	12,048	28.33	102.59	315.35	8,137	41.95	4.02	1.29	5.06	42,029	325,516	42,572	346,396	543	20,880
Sub-Total	**3240**																						**999,878**	**7,738,289**	**1,017,173**	**8,313,504**	**17,295**	**575,215**

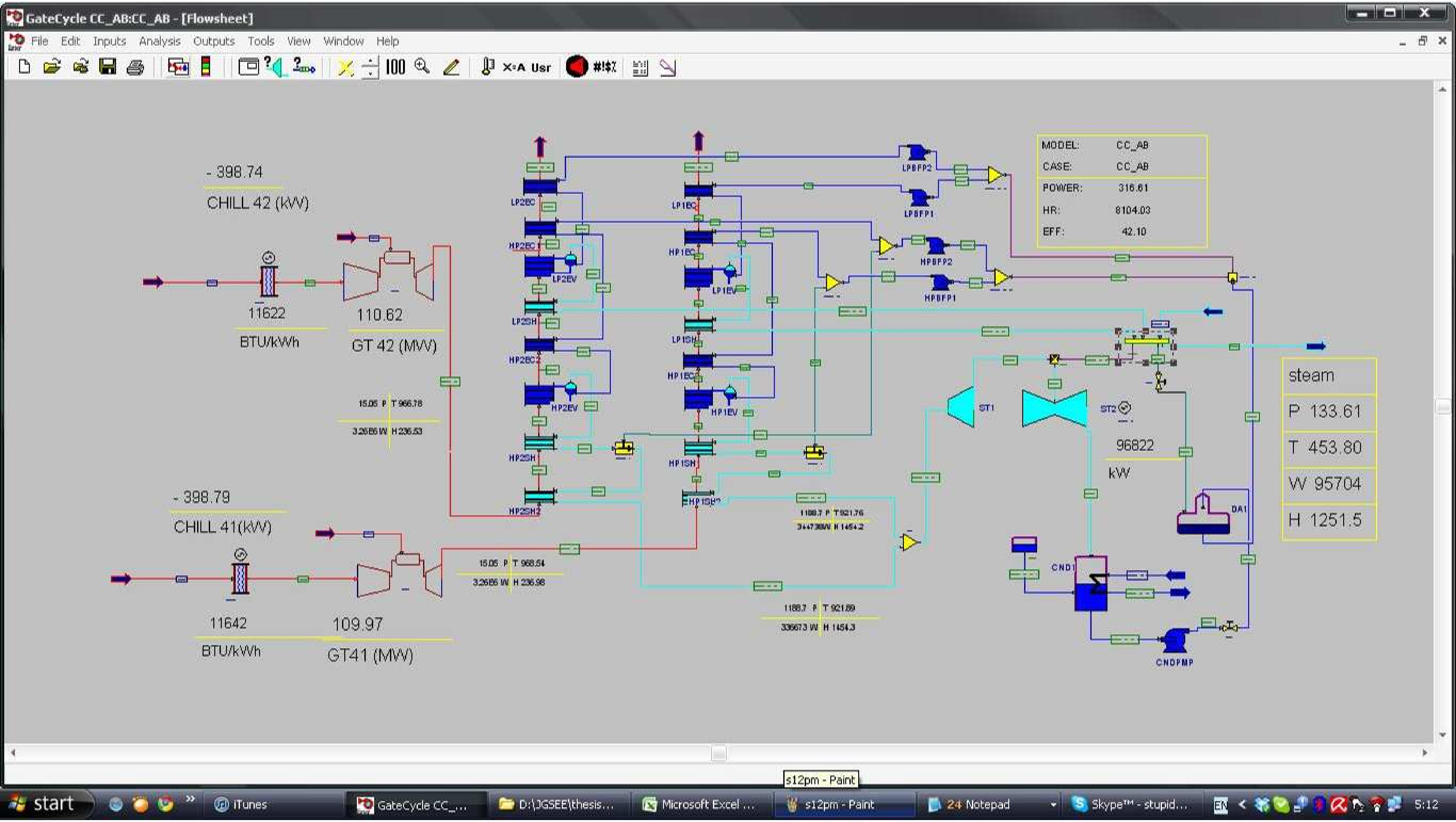
Mechanical Chiller System Performance Summary

	DB (^{o}C)	DB (^{o}C)	%RH
Design criteria	15.0		100

Period	% of
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load from Mechanical Chiller (Inc. pump and cooling tower) 1 kW/TR

		No	Mechanical Chiller																				Total Summary					
Month	Approx. Service Hour			GT41						GT42						ST	Net						No Chiller		Mechanical Chiller		Incremental	
		DB (^{o}C)	DB (^{o}C)	Output (MW)	Cooling Load (TR)	Parasitic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Cooling Load (TR)	Parasitic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Output (MW)	Heat rate (BTU/kWh)	Eff (%)	Output Increase (MW)	Output Increase (%)	Heat Rate Changed (%)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)
Nov - Feb																											0	0
1:00 AM	90	26.0	15	109.97	2,715.7	-2,715.7	107.25	11,937	28.59	110.62	2,715.4	-2,715.4	107.90	11,914	28.65	103.29	318.45	8,058	42.36	4.89	1.56	3.96	28,220	218,720	28,660	230,931	440	12,211
2:00 AM	90	25.7	15	109.97	2,655.8	-2,655.8	107.31	11,930	28.61	110.62	2,655.4	-2,655.4	107.96	11,908	28.66	103.43	318.71	8,051	42.39	4.63	1.47	3.86	28,267	219,110	28,684	230,931	417	11,820
3:00 AM	90	25.3	15	109.97	2,567.8	-2,567.8	107.40	11,920	28.63	110.62	2,567.5	-2,567.5	108.05	11,898	28.69	103.60	319.05	8,042	42.44	4.43	1.41	3.73	28,316	219,524	28,715	230,931	399	11,407
4:00 AM	90	25.0	15	109.97	2,508.2	-2,508.2	107.46	11,914	28.65	110.62	2,507.9	-2,507.9	108.11	11,892	28.70	103.74	319.32	8,036	42.47	4.22	1.34	3.63	28,359	219,892	28,738	230,931	379	11,039
5:00 AM	90	24.7	15	109.97	2,444.5	-2,444.5	107.53	11,907	28.66	110.62	2,444.3	-2,444.3	108.18	11,885	28.72	103.86	319.56	8,030	42.51	4.06	1.29	3.55	28,395	220,183	28,760	230,931	365	10,748
6:00 AM	90	24.4	15	109.97	2,331.9	-2,331.9	107.64	11,894	28.69	110.62	2,331.6	-2,331.6	108.29	11,872	28.75	103.99	319.91	8,021	42.55	3.99	1.26	3.41	28,433	220,526	28,792	230,931	360	10,405
7:00 AM	90	24.3	15	109.97	2,329.3	-2,329.3	107.64	11,894	28.70	110.62	2,329.1	-2,329.1	108.29	11,872	28.75	104.03	319.96	8,020	42.56	3.92	1.24	3.39	28,443	220,616	28,796	230,931	353	10,315
8:00 AM	90	25.2	15	109.97	2,370.0	-2,370.0	107.60	11,898	28.68	110.62	2,369.7	-2,369.7	108.25	11,876	28.74	103.63	319.48	8,031	42.50	4.76	1.51	3.59	28,325	219,607	28,753	230,931	429	11,324
9:00 AM	90	26.7	15	109.97	2,498.8	-2,498.8	107.47	11,913	28.65	110.62	2,499.1	-2,499.1	108.12	11,891	28.70	102.96	318.55	8,055	42.37	6.09	1.95	3.99	28,121	217,830	28,670	230,931	548	13,100
10:00 AM	90	28.0	15	109.97	2,601.4	-2,601.4	107.37	11,924	28.62	110.62	2,601.1	-2,601.1	108.02	11,902	28.68	102.36	317.75	8,075	42.27	7.30	2.35	4.37	27,941	216,170	28,598	230,931	657	14,761
11:00 AM	90	29.1	15	109.97	2,726.6	-2,726.6	107.24	11,938	28.59	110.62	2,726.3	-2,726.3	107.89	11,916	28.64	101.89	317.03	8,094	42.17	8.17	2.65	4.64	27,797	214,992	28,533	230,931	735	15,938
12:00 PM	90	29.8	15	109.97	2,809.0	-2,809.0	107.16	11,947	28.57	110.62	2,808.7	-2,808.7	107.81	11,925	28.62	101.55	316.53	8,106	42.10	8.82	2.87	4.90	27,693	214,009	28,487	230,931	794	16,921
1:00 PM	90	30.6	15	109.97	2,953.3	-2,953.3	107.02	11,963	28.53	110.62	2,952.9	-2,952.9	107.67	11,941	28.58	101.20	315.88	8,123	42.02	9.42	3.07	5.15	27,582	213,065	28,429	230,931	848	17,866
2:00 PM	90	31.0	15	109.97	3,032.6	-3,032.6	106.94	11,972	28.51	110.62	3,032.3	-3,032.3	107.59	11,950	28.56	101.02	315.54	8,132	41.97	9.69	3.17	5.29	27,527	212,591	28,399	230,931	872	18,340
3:00 PM	90	31.2	15	109.97	3,084.8	-3,084.8	106.89	11,978	28.49	110.62	3,084.5	-3,084.5	107.54	11,955	28.55	100.95	315.37	8,136	41.95	9.74	3.19	5.35	27,507	212,427	28,384	230,931	876	18,504
4:00 PM	90	31.2	15	109.97	3,156.8	-3,156.8	106.81	11,986	28.47	110.62	3,156.5	-3,156.5	107.46	11,963	28.53	100.95	315.22	8,140	41.93	9.62	3.15	5.40	27,505	212,424	28,370	230,931	866	18,507
5:00 PM	90	30.6	15	109.97	3,228.7	-3,228.7	106.74	11,994	28.46	110.62	3,228.3	-3,228.3	107.39	11,971	28.51	101.20	315.34	8,137	41.94	8.83	2.88	5.32	27,585	213,130	28,380	230,931	795	17,800
6:00 PM	90	29.5	15	109.97	3,190.8	-3,190.8	106.78	11,990	28.47	110.62	3,190.4	-3,190.4	107.43	11,967	28.52	101.71	315.92	8,122	42.02	7.68	2.49	5.03	27,742	214,518	28,433	230,931	691	16,413
7:00 PM	90	28.5	15	109.97	3,064.6	-3,064.6	106.91	11,976	28.50	110.62	3,064.3	-3,064.3	107.56	11,953	28.55	102.18	316.64	8,104	42.12	6.84	2.21	4.71	27,882	215,777	28,497	230,931	615	15,153
8:00 PM	90	28.0	15	109.97	3,015.9	-3,015.9	106.95	11,970	28.51	110.62	3,015.5	-3,015.5	107.60	11,948	28.57	102.37	316.93	8,096	42.16	6.46	2.08	4.58	27,942	216,312	28,523	230,931	581	14,618
9:00 PM	90	27.7	15	109.97	2,980.2	-2,980.2	106.99	11,966	28.52	110.62	2,979.8	-2,979.8	107.64	11,944	28.58	102.52	317.15	8,090	42.19	6.17	1.99	4.48	27,988	216,735	28,544	230,931	556	14,196
10:00 PM	90	27.3	15	109.97	2,921.1	-2,921.1	107.05	11,960	28.54	110.62	2,920.8	-2,920.8	107.70	11,937	28.59	102.71	317.46	8,083	42.23	5.84	1.87	4.34	28,046	217,249	28,571	230,931	526	13,682
11:00 PM	90	26.8	15	109.97	2,867.8	-2,867.8	107.10	11,954	28.55	110.62	2,867.5	-2,867.5	107.75	11,931	28.61	102.91	317.76	8,075	42.27	5.46	1.75	4.22	28,107	217,764	28,599	230,931	492	13,166
12:00 AM	90	26.3	15	109.97	2,793.9	-2,793.9	107.18	11,945	28.57	110.62	2,793.6	-2,793.6	107.83	11,923	28.63	103.13	318.13	8,066	42.32	5.10	1.63	4.09	28,173	218,305	28,631	230,931	459	12,626
Sub-Total	**2160**																						**671,895**	**5,201,476**	**685,947**	**5,542,336**	**14,052**	**340,860**
Total	**7128**				**4,694.5**						**4,694.0**												**2201571.7**	**17036887.7**	**2244018.4**	**18289709.4**	**42,447**	**1,252,822**



- 398.74
CHILL 42 (kW)

11622
BTU/kWh

110.62
GT 42 (MW)

15.05 P T 966.78
3.2686 W H 236.53

- 398.79
CHILL 41(kW)

11642
BTU/kWh

109.97
GT41 (MW)

15.05 P T 968.54
3.2686 W H 236.98

1188.7 P T 921.76
344738W H 1454.2

1188.7 P T 921.89
336673 W H 1454.3

MODEL:	CC_AB
CASE:	CC_AB
POWER:	316.61
HR:	8104.03
EFF:	42.10

96822
kW

steam
P 133.61
T 453.80
W 95704
H 1251.5

Absorption Chiller System Performance Summary

	DB (^{o}C)	DB (^{o}C)	%RH
Design criteria	15.0		100

Period	% of
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load from Mechanical Chiller (Inc. pump and cooling tower)	0.1	kW/TR
Approximately Steam Consumption	12	lbm/h/TR

		No	Absorption Chiller																					Total Summary					
				GT41						GT42						ST		Net						No Chiller		Absorption Chiller		Incremental	
Month	**Approx. Service Hour**	**DB (^{o}C)**	**DB (^{o}C)**	**Output (MW)**	**Cooling Load (TR)**	**Parasistic load (kW)**	**Net Output (MW)**	**Heat Rate (BTU/kWh)**	**EFF (%)**	**Output (MW)**	**Cooling Load (TR)**	**Parasistic load (kW)**	**Net Output (MW)**	**Heat Rate (BTU/kWh)**	**EFF (%)**	**MW**	**Steam Consumption (lb/hr)**	**Output (MW)**	**Heat rate (BTU/kWh)**	**Eff (%)**	**Output Increase (MW)**	**Output Increase (%)**	**Heat Rate Changed (%)**	**Total MWh**	**Fuel Consumption (MMBTU)**	**Total MWh**	**Fuel Consumption (MMBTU)**	**Total MWh**	**Fuel Consumption (MMBTU)**
Mar-May																													
1:00 AM	72	28.6	15	109.97	4,184.5	-418.5	109.55	11,686	29.20	110.62	4,184.0	-418.4	110.20	11,666	29.26	96.18	100422	315.94	8,122	42.02	6.20	2.00	4.92	22,301	172,622	22,747	184,745	446	12,122
2:00 AM	72	28.4	15	109.97	4,197.8	-419.8	109.55	11,687	29.20	110.62	4,197.3	-419.7	110.20	11,666	29.26	96.28	100741	316.03	8,119	42.04	5.98	1.93	4.87	22,324	172,828	22,754	184,745	431	11,917
3:00 AM	72	28.2	15	109.97	4,189.1	-418.9	109.55	11,687	29.20	110.62	4,188.6	-418.9	110.20	11,666	29.26	96.37	100532	316.12	8,117	42.05	5.85	1.89	4.80	22,339	173,017	22,761	184,745	421	11,728
4:00 AM	72	28.0	15	109.97	4,191.6	-419.2	109.55	11,687	29.20	110.62	4,191.2	-419.1	110.20	11,666	29.26	96.45	100594	316.20	8,115	42.06	5.59	1.80	4.78	22,364	173,194	22,766	184,745	403	11,550
5:00 AM	72	27.9	15	109.97	4,182.3	-418.2	109.55	11,686	29.20	110.62	4,181.8	-418.2	110.20	11,666	29.26	96.52	100369	316.27	8,113	42.07	5.41	1.74	4.76	22,382	173,338	22,771	184,745	389	11,406
6:00 AM	72	27.7	15	109.97	4,201.6	-420.2	109.55	11,687	29.20	110.62	4,201.1	-420.1	110.20	11,666	29.26	96.57	100832	316.32	8,112	42.07	5.27	1.69	4.73	22,396	173,455	22,775	184,745	379	11,290
7:00 AM	72	28.0	15	109.97	4,211.4	-421.1	109.55	11,687	29.20	110.62	4,210.9	-421.1	110.20	11,666	29.25	96.46	101068	316.21	8,115	42.06	5.50	1.77	4.79	22,371	173,230	22,767	184,745	396	11,515
8:00 AM	72	29.4	15	109.97	4,309.0	-430.9	109.54	11,688	29.20	110.62	4,308.5	-430.9	110.19	11,667	29.25	95.81	103410	315.54	8,132	41.97	7.12	2.31	5.09	22,206	171,831	22,719	184,745	513	12,913
9:00 AM	72	30.9	15	109.97	4,303.2	-430.3	109.54	11,688	29.20	110.62	4,302.7	-430.3	110.19	11,667	29.25	95.16	103271	314.89	8,149	41.88	7.79	2.54	5.18	22,111	171,306	22,672	184,745	561	13,438
10:00 AM	72	32.3	15	109.97	4,384.9	-438.5	109.53	11,689	29.20	110.62	4,384.4	-438.4	110.18	11,668	29.25	94.55	105232	314.27	8,165	41.80	10.26	3.37	5.70	21,889	169,076	22,627	184,745	739	15,668
11:00 AM	72	32.8	15	109.97	4,543.3	-454.3	109.52	11,690	29.20	110.62	4,542.8	-454.3	110.17	11,670	29.25	94.33	109033	314.01	8,171	41.77	10.79	3.56	5.82	21,832	168,580	22,609	184,745	777	16,165
12:00 PM	72	33.2	15	109.97	4,608.7	-460.9	109.51	11,691	29.19	110.62	4,608.1	-460.8	110.16	11,671	29.24	94.15	110602	313.82	8,176	41.74	11.23	3.71	6.00	21,786	168,041	22,595	184,745	809	16,704
1:00 PM	72	33.5	15	109.97	4,618.8	-461.9	109.51	11,691	29.19	110.62	4,618.3	-461.8	110.16	11,671	29.24	94.03	110845	313.70	8,180	41.73	11.49	3.80	5.97	21,759	167,953	22,586	184,745	827	16,791
2:00 PM	72	33.5	15	109.97	4,612.2	-461.2	109.51	11,691	29.19	110.62	4,611.7	-461.2	110.16	11,671	29.24	94.00	110687	313.67	8,180	41.72	11.58	3.83	5.99	21,751	167,878	22,584	184,745	834	16,866
3:00 PM	72	33.5	15	109.97	4,690.4	-469.0	109.50	11,692	29.19	110.62	4,689.9	-469.0	110.15	11,671	29.24	94.02	112564	313.67	8,180	41.72	11.50	3.81	5.98	21,756	167,928	22,584	184,745	828	16,817
4:00 PM	72	33.3	15	109.97	4,694.5	-469.5	109.50	11,692	29.19	110.62	4,694.0	-469.4	110.15	11,672	29.24	94.11	112662	313.76	8,178	41.73	11.29	3.73	5.93	21,778	168,138	22,591	184,745	813	16,607
5:00 PM	72	33.0	15	109.97	4,672.9	-467.3	109.50	11,692	29.19	110.62	4,672.3	-467.2	110.15	11,671	29.24	94.23	112142	313.89	8,175	41.75	11.11	3.67	5.81	21,800	168,424	22,600	184,745	800	16,320
6:00 PM	72	32.3	15	109.97	4,615.4	-461.5	109.51	11,691	29.19	110.62	4,614.8	-461.5	110.16	11,671	29.24	94.53	110762	314.20	8,166	41.79	10.26	3.38	5.68	21,884	169,098	22,622	184,745	739	15,646
7:00 PM	72	31.4	15	109.97	4,446.1	-444.6	109.53	11,689	29.20	110.62	4,445.6	-444.6	110.18	11,669	29.25	94.94	106700	314.64	8,155	41.85	9.29	3.04	5.48	21,985	169,979	22,654	184,745	669	14,765
8:00 PM	72	30.8	15	109.97	4,324.0	-432.4	109.54	11,688	29.20	110.62	4,323.5	-432.4	110.19	11,668	29.25	95.22	103770	314.94	8,147	41.89	8.64	2.82	5.32	22,053	170,593	22,676	184,745	622	14,152
9:00 PM	72	30.2	15	109.97	4,294.7	-429.5	109.54	11,688	29.20	110.62	4,294.2	-429.4	110.19	11,667	29.25	95.46	103067	315.19	8,141	41.93	8.02	2.61	5.22	22,116	171,111	22,694	184,745	578	13,634
10:00 PM	72	29.7	15	109.97	4,250.6	-425.1	109.54	11,687	29.20	110.62	4,250.1	-425.0	110.19	11,667	29.25	95.68	102008	315.42	8,135	41.95	7.49	2.43	5.13	22,171	171,560	22,710	184,745	539	13,184
11:00 PM	72	29.4	15	109.97	4,233.5	-423.4	109.55	11,687	29.20	110.62	4,233.0	-423.3	110.20	11,667	29.25	95.82	101598	315.57	8,131	41.97	7.10	2.30	5.08	22,210	171,866	22,721	184,745	511	12,879
12:00 AM	72	29.2	15	109.97	4,273.2	-427.3	109.54	11,687	29.20	110.62	4,272.7	-427.3	110.19	11,667	29.25	95.93	102551	315.66	8,129	41.99	6.83	2.21	5.04	22,235	172,077	22,728	184,745	492	12,668
Sub-Total	**1728**																							**529,799**	**4,097,123**	**544,313**	**4,433,869**	**14,514**	**336,746**

Absorption Chiller System Performance Summary

	DB (^{o}C)	DB (^{o}C)	%RH
Design criteria	15.0		100

Period	% of
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load from Mechanical Chiller (Inc. pump and cooling tower)	0.1	kW/TR
Approximately Steam Consumption	12	lbm/h/TR

		No	Absorption Chiller																					Total Summary					
				GT41						GT42						ST		Net						No Chiller		Absorption Chiller		Incremental	
Month	Approx. Service Hour	DB (^{o}C)	DB (^{o}C)	Output (MW)	Cooling Load (TR)	Parasistic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Cooling Load (TR)	Parasistic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Steam Consumption (lb/hr)	Output (MW)	Heat rate (BTU/kWh)	Eff (%)	Output Increase (MW)	Output Increase (%)	Heat Rate Changed (%)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)
Jun - Oct																												0	0
1:00 AM	135	27.5	15	109.97	3,987.9	-398.8	109.57	11,684	29.21	110.62	3,987.4	-398.7	110.22	11,664	29.26	96.82	95704	316.61	8,104	42.11	5.25	1.69	4.61	42,034	325,629	42,743	346,396	709	20,768
2:00 AM	135	27.3	15	109.97	3,964.6	-396.5	109.57	11,684	29.21	110.62	3,964.2	-396.4	110.22	11,664	29.26	96.92	95146	316.71	8,102	42.13	5.07	1.63	4.59	42,072	325,899	42,756	346,396	685	20,497
3:00 AM	135	27.2	15	109.97	3,925.4	-392.5	109.58	11,684	29.21	110.62	3,924.9	-392.5	110.23	11,663	29.26	97.04	94204	316.84	8,098	42.14	4.96	1.59	4.53	42,104	326,184	42,774	346,396	669	20,212
4:00 AM	135	27.1	15	109.97	3,932.5	-393.3	109.58	11,684	29.21	110.62	3,932.1	-393.2	110.23	11,663	29.26	97.04	94375	316.84	8,098	42.14	4.90	1.57	4.54	42,112	326,235	42,773	346,396	662	20,161
5:00 AM	135	27.4	15	109.97	4,075.2	-407.5	109.56	11,685	29.21	110.62	4,074.7	-407.5	110.21	11,665	29.26	96.73	97799	316.50	8,107	42.10	4.95	1.59	4.65	42,059	325,821	42,728	346,396	669	20,575
6:00 AM	135	27.8	15	109.97	4,310.0	-431.0	109.54	11,688	29.20	110.62	4,309.6	-431.0	110.19	11,667	29.25	96.53	103435	316.25	8,113	42.07	5.34	1.72	4.76	41,974	325,083	42,694	346,396	721	21,313
7:00 AM	135	28.5	15	109.97	4,570.5	-457.1	109.51	11,691	29.19	110.62	4,570.0	-457.0	110.16	11,670	29.25	96.24	109686	315.92	8,122	42.02	5.96	1.92	4.90	41,844	323,987	42,649	346,396	805	22,409
8:00 AM	135	29.4	15	109.97	4,610.9	-461.1	109.51	11,691	29.19	110.62	4,610.4	-461.0	110.16	11,671	29.24	95.84	110656	315.51	8,133	41.97	6.99	2.27	5.11	41,650	322,262	42,593	346,396	944	24,134
9:00 AM	135	30.4	15	109.97	4,667.8	-466.8	109.50	11,692	29.19	110.62	4,667.2	-466.7	110.15	11,671	29.24	95.39	112020	315.04	8,145	41.91	8.08	2.63	5.29	41,440	320,564	42,531	346,396	1,091	25,832
10:00 AM	135	31.1	15	109.97	4,581.3	-458.1	109.51	11,691	29.19	110.62	4,580.8	-458.1	110.16	11,670	29.25	95.08	109945	314.75	8,152	41.87	8.90	2.91	5.40	41,289	319,355	42,491	346,396	1,202	27,041
11:00 AM	135	31.6	15	109.97	4,512.8	-451.3	109.52	11,690	29.20	110.62	4,512.2	-451.2	110.17	11,670	29.25	94.87	108300	314.56	8,157	41.84	9.44	3.09	5.51	41,191	318,451	42,465	346,396	1,274	27,945
12:00 PM	135	31.7	15	109.97	4,386.4	-438.6	109.53	11,689	29.20	110.62	4,385.9	-438.6	110.18	11,668	29.25	94.80	105268	314.51	8,158	41.83	9.65	3.17	5.55	41,156	318,096	42,459	346,396	1,303	28,300
1:00 PM	135	31.9	15	109.97	4,346.9	-434.7	109.54	11,688	29.20	110.62	4,346.4	-434.6	110.19	11,668	29.25	94.74	104320	314.46	8,160	41.83	9.80	3.22	5.59	41,130	317,836	42,453	346,396	1,323	28,560
2:00 PM	135	31.7	15	109.97	4,390.9	-439.1	109.53	11,689	29.20	110.62	4,390.4	-439.0	110.18	11,668	29.25	94.82	105376	314.53	8,158	41.84	9.59	3.15	5.55	41,167	318,186	42,462	346,396	1,295	28,210
3:00 PM	135	31.3	15	109.97	4,363.4	-436.3	109.53	11,688	29.20	110.62	4,362.9	-436.3	110.18	11,668	29.25	94.97	104716	314.69	8,154	41.86	9.24	3.02	5.46	41,236	318,822	42,483	346,396	1,247	27,574
4:00 PM	135	31.0	15	109.97	4,285.2	-428.5	109.54	11,688	29.20	110.62	4,284.7	-428.5	110.19	11,667	29.25	95.14	102839	314.87	8,149	41.88	8.83	2.89	5.37	41,316	319,514	42,508	346,396	1,192	26,882
5:00 PM	135	30.4	15	109.97	4,218.9	-421.9	109.55	11,687	29.20	110.62	4,218.4	-421.8	110.20	11,666	29.25	95.37	101248	315.12	8,143	41.92	8.28	2.70	5.25	41,423	320,479	42,541	346,396	1,118	25,917
6:00 PM	135	29.8	15	109.97	4,119.0	-411.9	109.56	11,686	29.21	110.62	4,118.6	-411.9	110.21	11,665	29.26	95.75	98851	315.51	8,133	41.97	7.68	2.50	5.09	41,557	321,579	42,594	346,396	1,037	24,817
7:00 PM	135	29.1	15	109.97	4,016.2	-401.6	109.57	11,685	29.21	110.62	4,015.8	-401.6	110.22	11,664	29.26	96.16	96384	315.95	8,121	42.03	7.03	2.28	4.93	41,704	322,790	42,653	346,396	949	23,606
8:00 PM	135	28.7	15	109.97	4,005.6	-400.6	109.57	11,685	29.21	110.62	4,005.1	-400.5	110.22	11,664	29.26	96.32	96128	316.11	8,117	42.05	6.76	2.19	4.81	41,762	323,423	42,675	346,396	913	22,973
9:00 PM	135	28.6	15	109.97	4,063.9	-406.4	109.56	11,685	29.21	110.62	4,063.4	-406.3	110.21	11,665	29.26	96.30	97528	316.08	8,118	42.04	6.31	2.04	4.88	41,819	323,695	42,670	346,396	851	22,701
10:00 PM	135	28.3	15	109.97	4,082.5	-408.3	109.56	11,685	29.21	110.62	4,082.1	-408.2	110.21	11,665	29.26	96.37	97975	316.14	8,116	42.05	5.98	1.93	4.84	41,871	324,147	42,679	346,396	807	22,249
11:00 PM	135	28.0	15	109.97	4,024.0	-402.4	109.57	11,685	29.21	110.62	4,023.5	-402.4	110.22	11,664	29.26	96.58	96570	316.37	8,111	42.08	5.70	1.84	4.75	41,940	324,739	42,709	346,396	770	21,657
12:00 AM	135	27.5	15	109.97	3,916.0	-391.6	109.58	11,684	29.21	110.62	3,915.5	-391.6	110.23	11,663	29.26	96.91	93978	316.71	8,102	42.13	5.39	1.73	4.60	42,029	325,516	42,757	346,396	728	20,880
Sub-Total	**3240**																							**999,878**	**7,738,289**	**1,022,840**	**8,313,504**	**22,963**	**575,215**

Absorption Chiller System Performance Summary

	DB (°C)	DB (°C)	%RH
Design criteria	15.0		100

Period	% of
March - May	80
June - October	90
November - February	75

Approximately Parasitic Load from Mechanical Chiller (Inc. pump and cooling tower)	0.1	kW/TR
Approximately Steam Consumption	12	lbm/h/TR

		No	Absorption Chiller																					Total Summary					
				GT41						GT42						ST		Net						No Chiller		Absorption Chiller		Incremental	
Month	Approx. Service Hour	DB (°C)	DB (°C)	Output (MW)	Cooling Load (TR)	Parasistic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	Output (MW)	Cooling Load (TR)	Parasistic load (kW)	Net Output (MW)	Heat Rate (BTU/kWh)	EFF (%)	MW	Steam Consumption (lb/hr)	Output (MW)	Heat rate (BTU/kWh)	Eff (%)	Output Increase (MW)	Output Increase (%)	Heat Rate Changed (%)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)	Total MWh	Fuel Consumption (MMBTU)
Nov - Feb																												0	0
1:00 AM	90	26.0	15	109.97	2,715.7	-271.6	109.70	11,671	29.24	110.62	2,715.4	-271.5	110.35	11,651	29.29	99.30	65173	319.35	8,035	42.48	5.79	1.85	3.67	28,220	218,720	28,741	230,931	521	12,211
2:00 AM	90	25.7	15	109.97	2,655.8	-265.6	109.70	11,670	29.25	110.62	2,655.4	-265.5	110.35	11,650	29.30	99.52	63734	319.58	8,029	42.51	5.50	1.75	3.58	28,267	219,110	28,762	230,931	495	11,820
3:00 AM	90	25.3	15	109.97	2,567.8	-256.8	109.71	11,669	29.25	110.62	2,567.5	-256.8	110.36	11,649	29.30	99.80	61624	319.88	8,021	42.55	5.26	1.67	3.47	28,316	219,524	28,789	230,931	473	11,407
4:00 AM	90	25.0	15	109.97	2,508.2	-250.8	109.72	11,669	29.25	110.62	2,507.9	-250.8	110.37	11,648	29.30	100.02	60193	320.11	8,016	42.58	5.01	1.59	3.38	28,359	219,892	28,810	230,931	451	11,039
5:00 AM	90	24.7	15	109.97	2,444.5	-244.5	109.73	11,668	29.25	110.62	2,444.3	-244.4	110.38	11,648	29.30	100.22	58666	320.32	8,010	42.61	4.82	1.53	3.30	28,395	220,183	28,829	230,931	434	10,748
6:00 AM	90	24.4	15	109.97	2,331.9	-233.2	109.74	11,667	29.25	110.62	2,331.6	-233.2	110.39	11,647	29.30	100.51	55962	320.63	8,003	42.65	4.72	1.49	3.18	28,433	220,526	28,857	230,931	424	10,405
7:00 AM	90	24.3	15	109.97	2,329.3	-232.9	109.74	11,667	29.25	110.62	2,329.1	-232.9	110.39	11,647	29.30	100.55	55901	320.67	8,002	42.65	4.64	1.47	3.16	28,443	220,616	28,861	230,931	417	10,315
8:00 AM	90	25.2	15	109.97	2,370.0	-237.0	109.73	11,667	29.25	110.62	2,369.7	-237.0	110.38	11,647	29.30	100.13	56876	320.25	8,012	42.60	5.53	1.76	3.34	28,325	219,607	28,822	230,931	497	11,324
9:00 AM	90	26.7	15	109.97	2,498.8	-249.9	109.72	11,669	29.25	110.62	2,499.1	-249.9	110.37	11,648	29.30	99.32	59975	319.41	8,033	42.49	6.96	2.23	3.71	28,121	217,830	28,747	230,931	626	13,100
10:00 AM	90	28.0	15	109.97	2,601.4	-260.1	109.71	11,670	29.25	110.62	2,601.1	-260.1	110.36	11,649	29.30	98.63	62430	318.70	8,051	42.39	8.25	2.66	4.06	27,941	216,170	28,683	230,931	742	14,761
11:00 AM	90	29.1	15	109.97	2,726.6	-272.7	109.70	11,671	29.24	110.62	2,726.3	-272.6	110.35	11,651	29.29	98.02	65435	318.07	8,067	42.31	9.21	2.98	4.30	27,797	214,992	28,626	230,931	829	15,938
12:00 PM	90	29.8	15	109.97	2,809.0	-280.9	109.69	11,672	29.24	110.62	2,808.7	-280.9	110.34	11,652	29.29	97.60	67412	317.63	8,078	42.25	9.92	3.23	4.54	27,693	214,009	28,586	230,931	893	16,921
1:00 PM	90	30.6	15	109.97	2,953.3	-295.3	109.67	11,673	29.24	110.62	2,952.9	-295.3	110.32	11,653	29.29	97.07	70874	317.07	8,092	42.18	10.61	3.46	4.76	27,582	213,065	28,537	230,931	955	17,866
2:00 PM	90	31.0	15	109.97	3,032.6	-303.3	109.67	11,674	29.24	110.62	3,032.3	-303.2	110.32	11,654	29.29	96.80	72779	316.78	8,100	42.14	10.93	3.57	4.88	27,527	212,591	28,511	230,931	984	18,340
3:00 PM	90	31.2	15	109.97	3,084.8	-308.5	109.66	11,675	29.23	110.62	3,084.5	-308.5	110.31	11,654	29.28	96.67	74032	316.64	8,103	42.12	11.01	3.60	4.93	27,507	212,427	28,498	230,931	991	18,504
4:00 PM	90	31.2	15	109.97	3,156.8	-315.7	109.65	11,676	29.23	110.62	3,156.5	-315.7	110.30	11,655	29.28	96.56	75760	316.52	8,107	42.10	10.91	3.57	4.96	27,505	212,424	28,487	230,931	982	18,507
5:00 PM	90	30.6	15	109.97	3,228.7	-322.9	109.65	11,676	29.23	110.62	3,228.3	-322.8	110.30	11,656	29.28	96.69	77484	316.63	8,104	42.12	10.13	3.30	4.89	27,585	213,130	28,497	230,931	912	17,800
6:00 PM	90	29.5	15	109.97	3,190.8	-319.1	109.65	11,676	29.23	110.62	3,190.4	-319.0	110.30	11,656	29.28	97.20	76574	317.15	8,091	42.19	8.90	2.89	4.63	27,742	214,518	28,543	230,931	801	16,413
7:00 PM	90	28.5	15	109.97	3,064.6	-306.5	109.66	11,675	29.23	110.62	3,064.3	-306.4	110.31	11,654	29.29	97.79	73547	317.77	8,075	42.27	7.97	2.57	4.34	27,882	215,777	28,599	230,931	717	15,153
8:00 PM	90	28.0	15	109.97	3,015.9	-301.6	109.67	11,674	29.24	110.62	3,015.5	-301.6	110.32	11,654	29.29	98.03	72377	318.02	8,068	42.30	7.55	2.43	4.22	27,942	216,312	28,622	230,931	680	14,618
9:00 PM	90	27.7	15	109.97	2,980.2	-298.0	109.67	11,674	29.24	110.62	2,979.8	-298.0	110.32	11,653	29.29	98.22	71520	318.22	8,063	42.33	7.24	2.33	4.13	27,988	216,735	28,639	230,931	651	14,196
10:00 PM	90	27.3	15	109.97	2,921.1	-292.1	109.68	11,673	29.24	110.62	2,920.8	-292.1	110.33	11,653	29.29	98.48	70103	318.48	8,057	42.36	6.86	2.20	4.01	28,046	217,249	28,664	230,931	618	13,682
11:00 PM	90	26.8	15	109.97	2,867.8	-286.8	109.68	11,672	29.24	110.62	2,867.5	-286.8	110.33	11,652	29.29	98.73	68824	318.75	8,050	42.40	6.45	2.07	3.90	28,107	217,764	28,688	230,931	581	13,166
12:00 AM	90	26.3	15	109.97	2,793.9	-279.4	109.69	11,672	29.24	110.62	2,793.6	-279.4	110.34	11,651	29.29	99.04	67050	319.07	8,042	42.44	6.04	1.93	3.78	28,173	218,305	28,716	230,931	544	12,626
Sub-Total	**2160**																							**671,895**	**5,201,476**	**688,114**	**5,542,336**	**16,219**	**340,860**
Total	**7128**				**273,441.0**						**273,410.2**													**2,201,572**	**17,036,888**	**2,255,267**	**18,289,709**	**53,695**	**1,252,822**

APPENDIX D

EXAMPLE FOR CALCULATION
OF PRIMARY ENERGY SAVINGS (PES)

PRIMARY ENERGY SAVINGS (PES)

Calculation of primary energy savings is proposed by the EU Directive and consists of four steps. The annual operation of the absorption chiller was selected for an example case study which is presented as follow.

Step 1: Determine all energy inputs and outputs

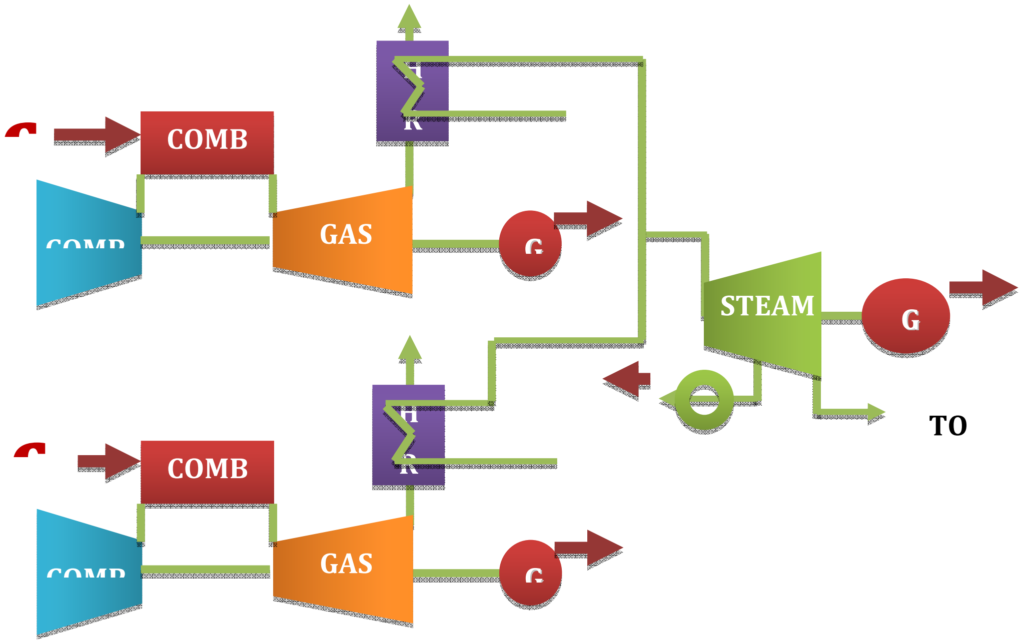


Figure D1 Schematic diagram for PES analysis

To determine the energy inputs and outputs first of the right boundaries have to be set. In this case there is no non-CHP useful heat energy generation. The energy inputs and outputs are those shown in Figure D1.

a) Total fuel energy (f)

Fuel energy for gas turbine GT41 (f_1) = 2,674,499 MWh

Fuel energy for gas turbine GT42 (f_2) = 2,685,685 MWh

Total fuel energy input (f) = $f_1 + f_2$ = 2,674,499 + 2,685,685 = 5,360,184 MWh

b) Total electrical/mechanical energy (p)

Electrical output from gas turbine GT 41 (p_1) = 783,866 MWh

Electrical output from gas turbine GT42 (p_2) = 788,499 MWh

Electrical output from steam turbine ST (p_3) = 688,356 MWh

Total electric output (p) = $p_1 + p_2 + p_3$ = 783,866 + 788,499 + 688,356 = 2,260,721 MWh

c) Total useful heat energy (q)

This plant is a combined cycle power plant, which has only generation of power. There is no generation of heat. The heat energy from steam extraction to absorption chiller can be determined to be indirect useful heat energy as per the EU directive.

From $Q = m.h$

Where Q is the thermal energy, MWh

m is mass flow rate of steam extraction to absorption chiller, lb/h

h is enthalpy of low pressure stream extraction, BTU/lb

steam condition extract:

T = 453.81 F, P = 133.61 psia, h = 1251.5 BTU/lb

Total useful heat (q) = q_f = 240,094 MWh

Step 2: Determine and exclude non-CHP useful heat energy

There are no possibilities to generate non-CHP useful heat. It is a plant without non-CHP useful heat energy generation. Therefore:

$$q_{non\text{-}CHP} = 0$$

$$f_{non\text{-}CHP,q} = 0$$

Step 3: Determine overall efficiency

CHP useful heat energy

$$q = q_f - q_{non\text{-}CHP} = 240{,}094 - 0 = 240{,}094 \text{ MWh}$$

$$p = 2{,}260{,}721\text{MWh}$$

$$f = f - f_{non\text{-}CHP} + q_f = 5{,}360{,}184 + 240094 = 5{,}600{,}278\text{MWh}$$

The overall efficiency is:

$$\eta = \frac{p + q_{CHP}}{f_{CHP} + f_{non-CHP}} = \frac{p + q - q_{non-CHP}}{f - f_{non-CHP}} = \frac{p + q}{f}$$

$$\eta = \frac{2{,}260{,}721 + 240{,}094 - 0}{5{,}600{,}278 - 0}$$

= 44.66 %

The determined overall efficiency (η) has to be compared with the value(s) in Annex II (a) of the EU Directive.

According to Annex I of the EU Directive a gas turbine with heat recovery belongs to type (d) therefore the threshold is 75%. As the plant runs short of this threshold, non-CHP electrical energy generation takes place and has to be determined.

Step 4: Determination of NON-CHP Electrical/Mechanical Energy and the Referring Fuel Energy

1) This system has steam extraction, which cause loss in steam power, where energy export leads to a change in electricity energy generation (related to constant fuel energy input). The power loss coefficient (β) is determined. According to this plant specification, steam turbine size is 109 MW with low pressure of 9.17 bar. The assumed power loss coefficient is prepared by interpolated calculation of given values for each size range of steam turbine and steam pressure as EU directive manual. The power loss coefficient (β) is given as 0.218
2) Efficiency of non-combined electrical energy generation:

$$\eta_{non-CHP,p} = \frac{p + \beta_{CHP}.q_{CHP}}{f - f_{non-CHP,q}} = \frac{2{,}260{,}721 + (0.218)(240{,}094)}{5{,}600{,}278 - 0} = 41.3\%$$

3) Power to heat ratio:

$$\sigma_{CHP} = \frac{\eta_{non-CHP,p} - \beta_{CHP} \cdot \eta_{CHP}}{\eta_{CHP} - \eta_{non-CHP,p}} = \frac{41.3\% - (0.218)(75\%)}{75\% - 41.3\ \%} = 0.74$$

4) CHP electrical energy:

$$p_{CHP} = q_{CHP} \cdot \sigma_{CHP} = (240{,}094)(0.74) = 177{,}669\ MWh$$

5) Non-CHP electrical energy:

$$p_{non-CHP} = p - p_{CHP} = 2{,}260{,}721 - 177{,}669 = 2{,}083{,}052\ \mathrm{MW}h$$

6) Fuel energy for non-CHP electrical energy generation:

$$f_{non-CHP,p} = \frac{p_{non-CHP}}{\eta_{non-CHP,p}} = \frac{2{,}083{,}052}{41.3\ \%} = 5{,}043{,}709\ \mathrm{MWh}$$

7) Fuel energy for CHP electrical energy generation:

$$f_{CHP} = f - f_{non-CHP,p} - f_{non-CHP,q} = 5{,}600{,}278 - 5{,}043{,}709 - 0$$

$$= 556{,}569\ \mathrm{MWh}$$

Table D1 Summary of CHP and non-CHP energies for absorption chiller case

	Total	CHP	non-CHP,q	non-CHP,p
p	2,260,721 MWh	177,669 MWh	0	2,083,052 MWh
q	240,094 MWh	240,094 MWh	0	0
f	5,600,278 MWh	556,569 MWh	0	5,043,709 MWh

Primary Energy Savings (PES)

According to the EU directive, the overall efficiency of gas turbine with heat recovery should be at least 75%. In this case, the overall efficiency is η = 44.66% therefore Equation 2.1 is applied for this case.

1. By using reference values in Thailand, in which 85% and 45 % are used for $REFH_\eta$ and $REFE_\eta$ respectively.

$$PES = \left(1 - \frac{1}{\frac{H_\eta}{REFH_\eta} + \frac{E_\eta}{REFE_\eta}}\right)100\%$$

$$H_\eta = \frac{240{,}094}{5{,}600{,}278} \mathrm{X}\, 100 = 4.29\ \%$$

$$E_\eta = \frac{2{,}260{,}721}{5{,}600{,}278} \mathrm{X}\, 100 = 40.37\ \%$$

$$PES = \left(1 - \frac{1}{\frac{4.29\%}{85\%} + \frac{40.37\%}{45\%}}\right)100\% \ = \ -5.53\%$$

2. By using reference efficiency, following the Commission Decision of 21 December 2006, establishing harmonised efficiency reference values for the separate production of electricity and heat in the application of Directive 2004/8/EC of the European Parliament and of the Council

According to Annex I, the reference efficiency for the separate production of electricity and heat is 32.8% and 90% respectively in which the reference efficiency for separate production of electricity was corrected to relate to the average climatic situation of Bangpakong Power Plant (Assume = 32.2^{o}C), the years of construction and the type of fuel

$$PES = \left(1 - \frac{1}{\frac{H_\eta}{REFH_\eta} + \frac{E_\eta}{REFE_\eta}}\right)100\%$$

$$PES = \left(1 - \frac{1}{\frac{4.29\%}{90\%} + \frac{40.37\%}{32.8\%}}\right)100\% \ = \ 21.78\%$$

APPENDIX E

INFORMATION FOR COST EFFCTIVENESS AND FEASIBILITY

Date: 9/7/2010

GIAC with Absorption Chiller

No.,	**Equipment/System**	**Descriptions**	**Investment** Mbaht / GTG 1 Set
1	Absorption chiller	5,000 RT Steam Chiller	88
2	Cooling tower/ Pump		28.33
3	Cooling coil/Filter system		21
4	Piping and Installation work		133.6
5	Commissioning / Training		3
6	Construction Management/ Engineering Fee		25
	Total		298.93
	VAT	7%	20.93
	Total (Excluded VAT)		**298.93**
	Total (Included VAT)		**319.86**

GIAC with Electric Chiller

No.,	**Equipment/System**	**Descriptions**	**Investment** Mbaht / GTG 1 Set
1	Electric chiller	5,000 RT	70
2	Cooling tower/ Pump		28.33
3	Cooling coil/Filter system		21
4	Piping and Installation work		121.5
5	Commissioning / Training		3
6	Construction Management/ Engineering Fee		25
	Total		268.83
	VAT	7%	18.82
	Total (Excluded VAT)		**268.83**
	Total (Included VAT)		**287.65**

APPENDIX F

CALCULATION

OF DEGRADATION ANALYSIS

DEGRADATION ANALYSIS

The result of degradation analysis indicates the current performance level as compared with the guaranteed performance.

1. BPK-C41

1.1 Gas Turbine Generator Net Power Output Degradation

The information is

- Factored fire hours (FFH) ~ 23,000 hrs.
- Interpolate Odeg% from Table B.2, from which get Odeg% is -4.01%
- OPT is output performance test (corrected) which is 97.88 MW
- GO is guaranteed output, which is 98.786 MW for GT-42, and assume GT-41's guaranteed output is equal to GT-42

According to the equation,

$$NOI = \frac{OPT - CGO}{CGO} \times 100$$

Where

CGO = GO x (1 – Odeg %/100)

= 98.786 x (1 – (-4.01)/100)

= 102.747 MW

Therefore

$$NOI = \frac{97.88 - 102.75}{102.75} \times 100 \; = -4.74\,\% \qquad ,NOI < 0$$

1.2 Gas Turbine Generator Net Heat Rate Degradation

The information is

- Factored fire hours (FFH) ~ 23,000 hrs.
- Interpolate Odeg% from Table B.2, from which Odeg% is -2.84 %
- HRPT is heat rate performance test (corrected) which is 12,689.386 kJ/kWh
- GHR is guaranteed heat rate, which is 11,590 MW for GT-42, and assume that GT-41's guaranteed heat rate is equal to GT-42

According to the equation,

$$NHRI = \frac{CGHR - HRPT}{CGHR} \times 100$$

Where

CGHR = GHR x (1 + Odeg %/100)

= 11,590 x (1 + (-2.84)/100)

= 11,261 kJ/kWh

Therefore

$$NHRI = \frac{11{,}261 - 12{,}689.386}{11{,}261} \times 100 = -12.68\,\% \qquad ,NHRI < 0$$

2. BPK-C42

2.1 Gas Turbine Generator Net Power Output Degradation

The information is

- Factored fire hours (FFH) ~ 27,000 hrs.
- Interpolate Odeg% from Table B.2, from which Odeg% is -3.83%
- OPT is output performance test (corrected) which is 97.74 MW
- GO is guaranteed output, which is 98.786 MW for GT-42, and assume that GT-41’s guarantee output is equal to GT-42

According to the equation,

$$NOI = \frac{OPT - CGO}{CGO} \times 100$$

Where

CGO = GO x (1 – Odeg %/100)

= 98.786 x (1 – (-3.83)/100)

= 102.570 MW

Therefore

$$NOI = \frac{97.74 - 102.57}{102.57} \times 100 = -4.71\,\% \qquad ,NOI < 0$$

2.2 Gas Turbine Generator Net Heat Rate Degradation

The information is

- Factored fire hours (FFH) ~ 27,000 hrs.
- Interpolate Odeg% from Table B.2 then we get Odeg% is -2.84 %
- HRPT is heat rate performance test (corrected) which is 12,695 kJ/kWh
- GHR is guaranteed heat rate which is 11,590 MW for GT-42 and assume GT-41’s guarantee heat rate is equal GT-42

From equation,

$$NHRI = \frac{CGHR - HRPT}{CGHR} \times 100$$

Where

CGHR = GHR x (1 + Odeg %/100)

= 11,590 x (1 + (-2.84)/100)

= 11,261 kJ/kWh

Therefore

$$NHRI = \frac{11,261 - 12,695}{11,261} \times 100 = -12.73\ \% \qquad ,NHRI < 0$$