International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 12, Issue 3 [March. 2023] PP: 155-169

Feasibility Study of a Gas Engine Trigeneration System with Alternative Heating Systems in an Indonesian Hotel

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ABSTRACT:*A trigeneration system needs one input fuel energy to produce three outputs consisting of electricity, hot water, and chilled water simultaneously, which is especially useful in a hotel. This system plays an essential role in improving energy utilization efficiency due to the low temperature of the waste heat recovered. A reliable analysis is needed to reveal their implementation to substitute the conventional energy system relying on electricity from the central power plant. A reasonable engineering model and data assumption are necessary to compare it. This research investigates the feasibility of a trigeneration system for a hotel as a case study, which has a total building area of 30,000 m^2 and has a peak load of electricity excluding HVAC 600 kW, a peak cooling load of 1000 RT, and a daily maximum hot water load of 3850 kWh. Three alternative trigeneration systems proposed are based on configuration variation of the water heater system. Each alternative was simulated by including the daily energy load profile for the hotel. Life cycle cost (LCC) analysis involves costs of investment, operation, and maintenance but excludes the cost elements having the same values as each system. Based on the simulation results, the fuel utilization efficiency of the alternative trigeneration system ranges from 86% to 88%. The highest annual LCC of the alternative trigeneration system is US$903,085. It is less than the LCC of a conventional system having US$1,166,121. The alternative trigeneration system that uses only a chiller-heater for the water heater is the most efficient and economical energy system by fuel consumption and annual LCC of 60345.19 MMBtu and US$867,982, respectively.*
Keywords*: trigeneration system, hotel, energy utilization,life cycle cost.*

Date of Submission: 06-03-2023 Date of acceptance: 19-03-2023

I. INTRODUCTION

Nowadays, improvement in energy utilization efficiency needs to realize energy conservation, besides other efforts to find other energy sources such as renewable energy. Improvement of energy utilization efficiency will not reduce fuel consumption but also greenhouse gas emissions, especially CO_2. Energy utilization efficiency increases by implementing a trigeneration system to substitute the conventional energy system that relies on electricity from the central power plant.

A trigeneration system is an energy system that can produce three energy outputs simultaneously electricity, cooling, and heating from one energy source. The system can utilize the heat that is generally wasted on an energy conversion process in conventional energy systems so that the energy utilization efficiency is relatively high. A trigeneration system is not a single technology but an integrated energy system for adapting energy needs. The system is suitable for commercial buildings such as a hotel. It refers to the hotel's energy needs that require electricity, cooling, and heating simultaneously. The trigeneration system implementation does not reduce the national energy consumption but the cost of supplying energy for the hotel.

Trigeneration system attracts the attention of many researchers to maximize fuel energy utilization efficiency. Shelar and Kulkarni [1] reported an effort of trigeneration system implementation based on a diesel engine for a hotel in India. Their research results show that the fuel utilization efficiency of the trigeneration system is up to 84%. Zhao et al. [2] reported on a trigeneration system application for a railway station in China with a power generation capacity is 3.14 MW and a fuel utilization efficiency of up to 95%. Meanwhile, Chen et al. [3] discussed on energy and economic benefits of trigeneration system implementation based on a biogas engine for sewage treatment plants in Hong Kong. Based on their research result, the average annual thermal efficiency of sewage treatment plants increases from 20.8% to 38.3%.

This paper discusses the feasibility of the trigeneration system implementation for a hotel by using several alternative systems to find a low life cycle cost(*LCC*) energy utilization system. The conventional system is used as a baseline to compare with alternative trigeneration systems. All proposed alternative trigeneration systems choose gas engines as prime movers due to referring to the previous results obtained for the airport cogeneration system [4, 5]. A reasonable engineering model and accurate data assumption are included to solve the case study. Alternative trigeneration systems are compared to the conventional system considering the energy and economic aspects. Other technical aspects are discussed in this paper.

II. TRIGENERATION SYSTEMS AND CONVENTIONAL SYSTEM

A trigeneration system is an energy system that can produce three energy outputs: electricity, cooling, and heating simultaneously. These outputs have resulted from an energy source as prime mover fuel. The trigeneration system is an extension of a cogeneration system that only produces two energy outputs: electricity and heating/cooling. The trigeneration system consists of a power generating unit to generate electricity that uses a prime mover such as a gas engine or gas turbine. A heat recovery unit utilizes the heat released by the prime mover. The recovered heat is adjusted to meet heating and cooling needs. The heat can be used for the cooling system as heat input to the absorption chiller, besides utilizing it to meet heating needs such as the water heating process. Another possibility is also for recovering waste heat released from the condenser and absorber of the absorption chiller or condenser from the centrifugal chiller. The fuel utilization factor of the trigeneration system is high because the waste heat is recovered to drive the cooling and heating systems.

A comparison of the trigeneration system and older fashioned energy system for a commercial building is illustrated in Figs. 1 and 2. Fig. 1 shows a schematic of the older system for a commercial building. The older system relies on electricity from a central power plant as an energy source to meet the hotel's energy needs. The electricity is utilized as a power input on many electrical types of equipment for carrying out activities in the hotel. Additionally, electricity is needed as power input on mechanical chillers for the cooling processes and power input on an electrical heater for the water heating process given in Figure 1(a). Another possible system is using a natural gas-fired heater to produce hot water independently and reduce electricity needs from the central power plant, as shown in Fig. 1(b).

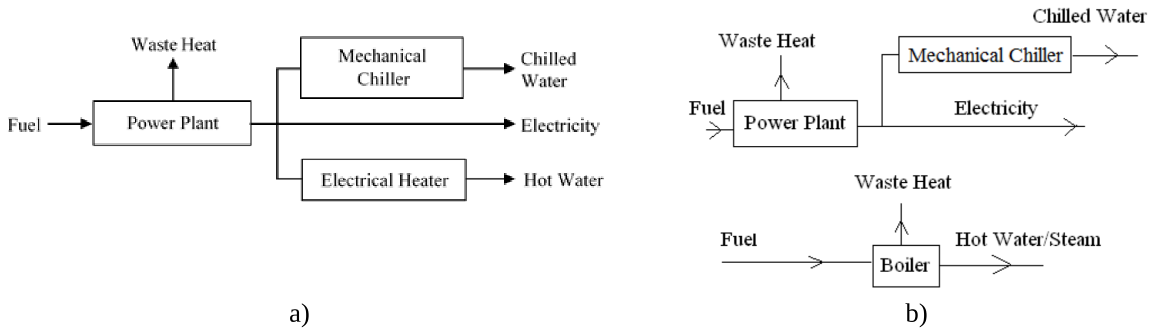

Fig. 1 Conventional energy system scheme

A trigeneration system is suitable to be applied in a building that needs electricity, cooling, and heating simultaneously. The different characteristics of the energy load profile for each building cause the development of alternative trigeneration systems for the building to vary. Fig. 2 shows a schematic of a trigeneration system alternative for a commercial building. The power generator that uses a gas engine or gas turbine as the prime mover is used to generate electricity. Waste heat from a prime mover is used as heat input to drive the absorption chiller. The heat is released from the condenser and absorber of the absorption chiller to heat the water. The system is suitable to be applied if the heat from the absorption chiller is unsatisfied to meet the load, so electricity is needed for power input on the electrical heater to support the water heating process. Besides that, other alternatives are possible to fitting the energy needs of the building.

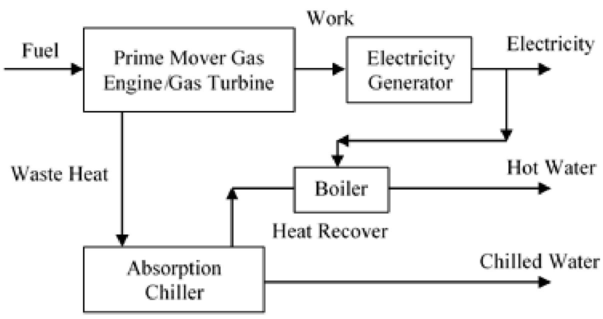

Fig. 2 Trigeneration system scheme

III. THREE ALTERNATIVE TRIGENERATION SYSTEMS

Simultaneous needs such as the electrical load on electrical equipment and lighting, water cooling for air conditioning, and water heating for the hotel services and also temperature difference for heat driving of prime mover, absorption chiller, and for water heating as current technology give a possibility to use waste heat from one process to other processes to improve energy utilization efficiency. A wide temperature range of heat driving for each process in the trigeneration system will give high fuel utilization efficiency. Three alternative trigeneration systems using a gas engine fueled by natural gas as prime mover are proposed. The prime mover drives a power generator for generating electricity, and variations of the configuration of air-conditioning system (HVAC) and water heating system are investigated.

System 1 is a trigeneration system consisting of a gas engine generator, absorption and centrifugal chillers, electric heater, and cooling tower as shown in Fig. 3. Gas engine-generator produces electricity, and the waste heat from the gas engine through engine cooling water and exhaust gas is recovered as a heat input for the absorption chiller. Chilled water to meet the cooling load of the hotel is not only produced by the absorption chiller, but also centrifugal chiller. The water heating system utilizes a heat released by the condenser and absorber of one of the absorption chillers and further heating using an electrical heater.

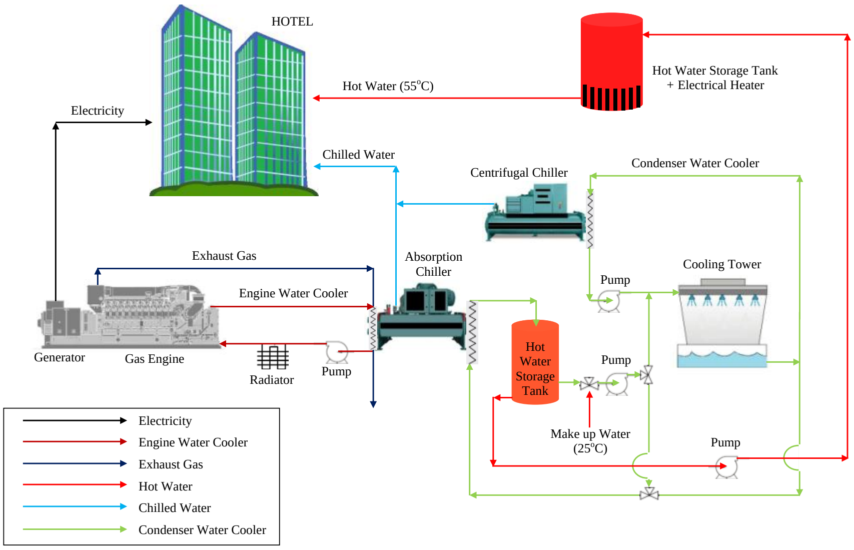

Fig. 3 The scheme of first alternative trigeneration system (System 1)

The water heating process of system 1 is initiated by the heating process of makeup water (25°C) through the absorber and condenser of the absorption chiller until 40°C and then this hot water product is stored in tank 1. The hot water from tank 1 is heated by an electrical heater until 55°C as ready-use water for the hotel and stored in tank 2. The operation time of the water heating process by the absorption chiller and electrical heater is regulated by water level control in each tank to accommodate the hot water load. An indirect-contact cooling tower is chosen to keep the water clean and free of other impurities. The cooling tower will not operate as long as needed for the heating process for tank 1.

System 2 is a trigeneration system similar to system 1, except the electric heater was replaced by a chiller as a heat pump as shown in Fig. 4. Therefore, the chiller heater has two functions, which first is heating hot water to 40°C from tank 1 to 55°C before being stored in tank 2, and second is producing chilled water together with absorption and centrifugal chillers. The waste heat of the centrifugal chiller is not recovered for hot water because using absorption chillers only satisfies the energy needs.

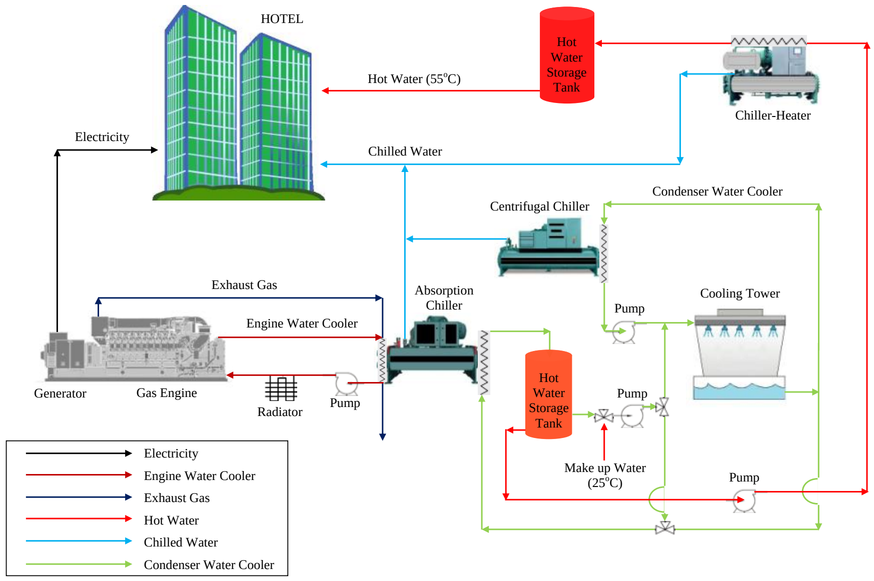

Fig. 4 The scheme of second alternative trigeneration system (System 2)

System 3 is a simplifying system of system 2 by directly heating the process of makeup water using a chiller-heater as shown in Figure 5. Makeup water (25°C) is heated through the heat recovery condenser of the chiller-heater until 55°C, and the hot water product is stored in the hot water tank. Unlike system 1 and system 2, an indirect-contact cooling tower is not used in system 3 since the water heating process does not involve the absorption chillers. This system will be a simple configuration of the water heating system.

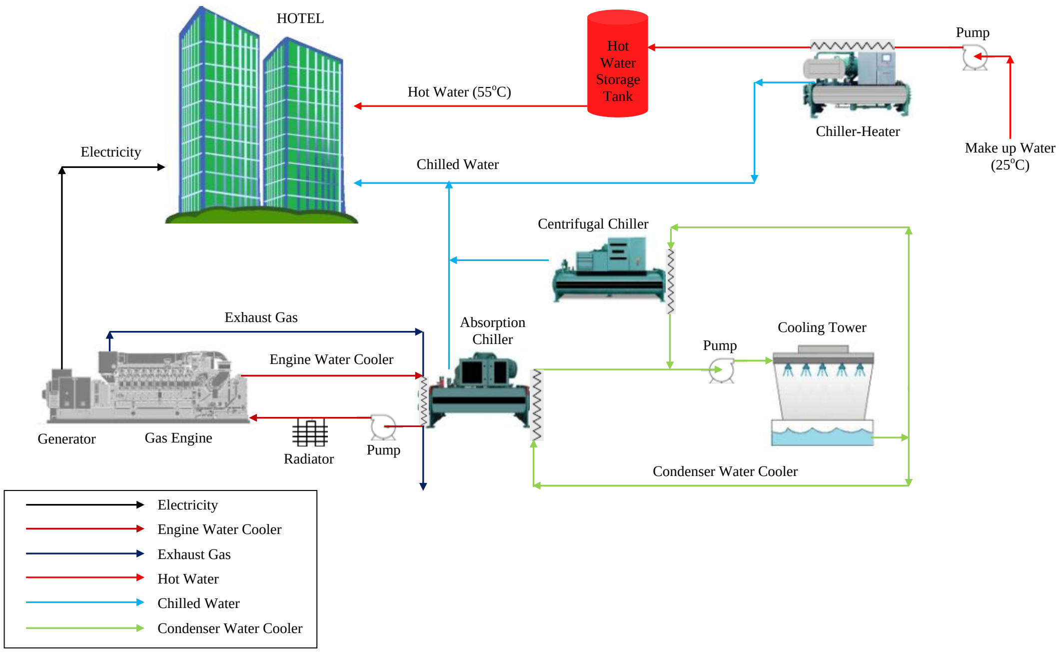

Fig. 5 The scheme of third alternative trigeneration system (System 3)

IV. DATA AND ENGINEERING MODEL

A case study of the trigeneration system application is needed to compare the characteristics of each alternative trigeneration system from energy and economy aspects. The case study of the trigeneration system application uses an object of a hotel that has a total building area of 30,000 m^2 with a number room of 300 rooms and an occupant capacity of 1000 persons. The energy composition of the hotel consists of a daily electricity peak load is 600 kW (except HVAC system), a daily cooling peak load of 1000 RT, a daily heating load of 3850 kWh (water volume of 11,0000 L, a water temperature of 55°C), and an average occupancy rate of 85%.

The daily energy load of the hotel is divided into three forms: electricity, cooling, and heating. The electricity supply lighting needs and other equipment to support the daily activity of the hotel. The cooling load is a load of air conditioning to cool the hotel, and the heating load is the water heating load for bathing, cooking, washing, and so forth. The daily energy load profile of the hotel usually changes over time, but the daily energy load is almost similar. Fig. 6 shows the daily energy load profile of the hotel.

The components of either trigeneration or conventional systems operated at the operating load conform to the energy load at a time interval. Operational characteristics of the system components at partial loads are used to determine the operating loads appropriately. Fig. 7 shows the characteristics of gas engine-generator efficiency. While Figs. 8–10 show the COP characteristic of the absorption chiller, centrifugal chiller, and chiller-heater.

Technical and economic data needed to conduct energy and economic analyses are given in Table 1. Operation and maintenance (OM) costs are included in these analyses and separated into electricity and fuel costs. The most sensitive data in economic analysis are electricity and fuel prices. Both prices will be varied and discussed further to reveal the economic characteristics of the systems.

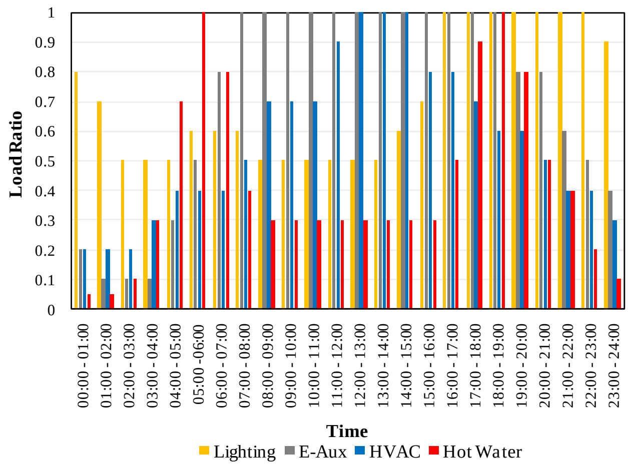

Fig. 6 The daily energy load profile of the hotel

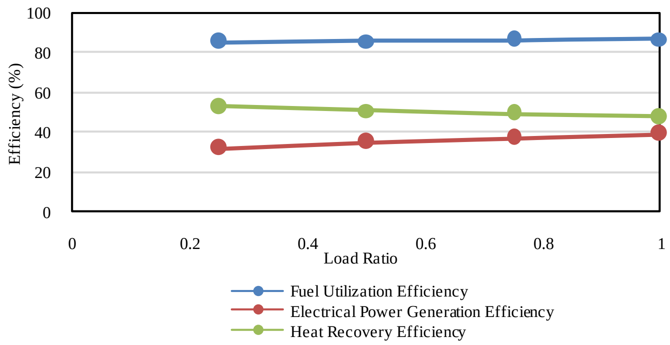

Fig. 7 The characteristic of gas engine-generator efficiency

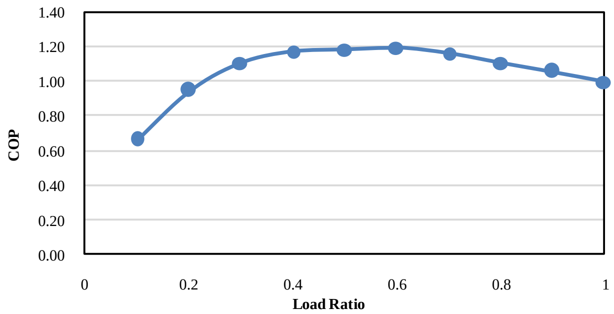

Fig. 8 The COP characteristic of absorption chiller

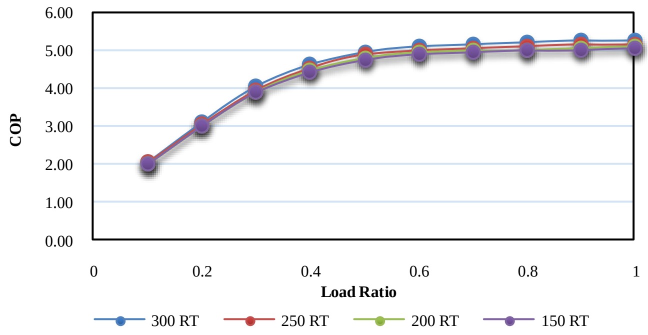

Fig. 9 The COP characteristic of centrifugal chiller

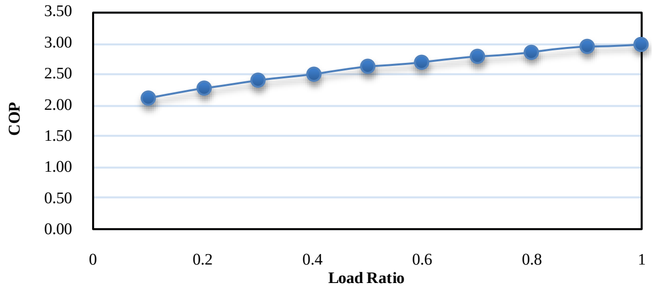

Fig. 10 The COP characteristic of chiller-heater

Table 1. Technical and economic data

Parameter		Value	Unit
Natural Gas		7	\$/MMBtu
Electricity		0.1	\$/kWh
Water		1	$\$/m^3$
Centrifugal Chiller		390	\$/RT
Chiller heater		350	\$/RT
Absorption Chiller		815	\$/RT
Gas Engine + Generator		460	\$/kWe
Genset		480	\$/kWe
Electrical Heater		40	\$/kW
Hot Water Storage Tank		2	\$/l
Cooling Tower (Include Pump + piping)	Direct Contact	170	\$/RT
	Indirect Contact	220	\$/TR
OM Gas Engine + Generator (Exclude Fuel)		0.010	\$/kWh
OM HVAC (Exclude Fuel/Electric and Chiller)		0.002	\$/RT-h
OM Centrifugal Chiller (Exclude Electricity)		0.003	\$/RT-h
OM Chiller-Heater (Exclude Electricity)		0.003	\$/RT-h
OM Absorption Chiller (Exclude Electricity)		0.005	\$/RT-h
E-Power of Absorption Chiller (Exclude AHU, FCU, CT, etc.)		0.035	kW/RT
Auxiliary E-Power (AHU, FCU, Second loop)		0.25	kW/RT
E-Power Consumption of Cooling Tower		0.085	kW/RT
Building Cost		300	$\$/m^2$
Machine Economic Life		15	Years
Building Economic Life		20	Years

Parameter	Value	Unit
Interest Rate	0.1	
Operating Day	365	Days

V. EVALUATION METHOD

Several evaluation methods used refer to the references that discusses the trigeneration and cogeneration systems [4–6]. Six main points discussed in this paper consist of the operation of the system component, the makeup of water needs of the cooling tower, fuel consumption, fuel utilization efficiency, calculation of the annual operational needs, and calculation of the annual *LCC*. The discussion of the six main points uses the methodology described by the flow diagram in Fig. 11. An explanation of the basic concept of the evaluation methods is given in this section.

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Operation scheduling of the system components includes the determination of the number of units and load percentage of the operating components on the time interval. The components consist of a gas engine generator, absorption chiller, centrifugal chiller, and chiller heater. Besides that, operation scheduling is also conducted on the components of the water heating system. The operation scheduling follows the daily energy load profile described previously. Daily simulation run to determine the daily operational needs of the system, such as clean water and fuel. The daily-operational needs will determine the amount of the annual operational needs of the system.

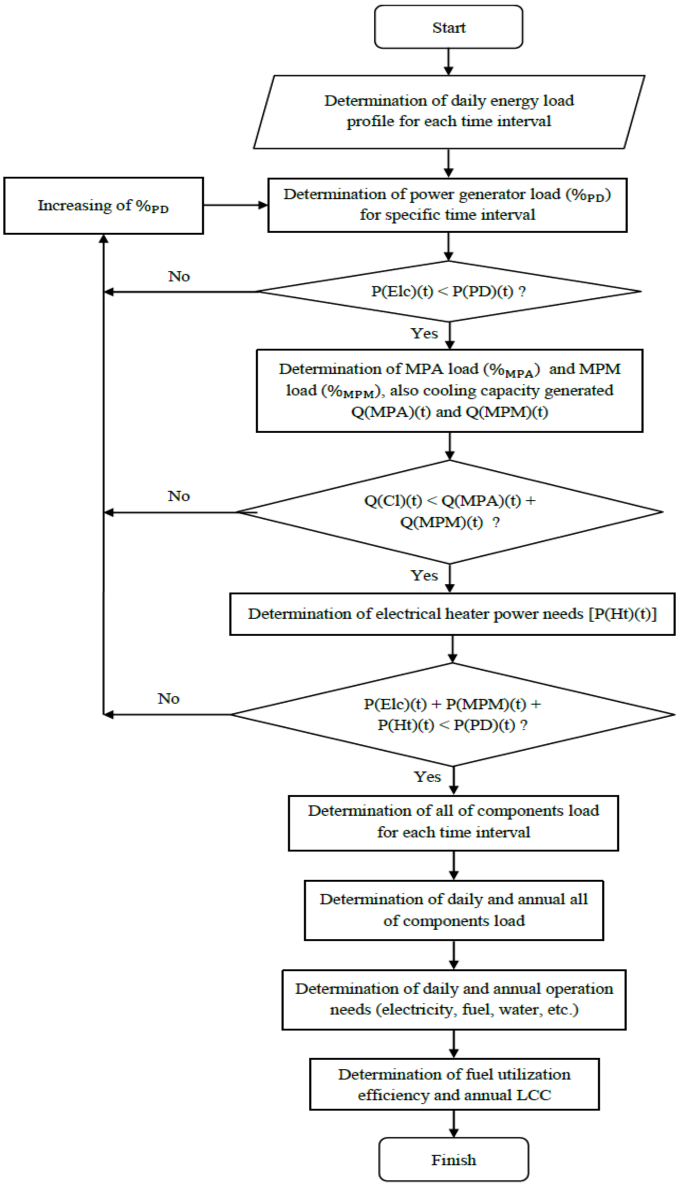
Makeup water needs of the cooling tower depend on the cooling load and ambient condition. The type of cooling tower also contributes to the amount of makeup water. The makeup water volume of the indirect-contact cooling tower is assumed to be 70% of the direct-contact cooling tower for the same capacity. The cooling process on the direct-contact cooling tower is dominated by evaporative cooling so that more water will evaporate. The makeup water flow rate of the cooling tower is varied under the operation load of the chiller. The total amount of makeup water needed for the cooling tower for each system is equal to the amount of makeup water needed for the indirect-contact and direct-contact cooling towers.

Natural gas fuel consumption by the trigeneration systems depends on the operation load of the gas engine generator. The fuel consumption relates to the energy input to the gas engine generator. The energy input to the gas engine generator is estimated using Eq. (1). Where q_{in} is energy input from fuel (kJ) and t is time (s).

$$q_{in} = \dot{Q}_{in} \times t \tag{1}$$

The fuel utilization efficiency is calculated using Eq. (2), where η_{fuel} is fuel utilization efficiency, $\dot{Q}_{loss}$ is energy loss in the system (kW), and $\dot{Q}_{fuel}$ is energy produced from fuel (kW). The fuel utilization efficiency of the trigeneration system is varied and depends on the operating load of the gas engine generator.

$$\eta_{fuel} = \frac{\dot{Q}_{fuel} - \dot{Q}_{loss}}{\dot{Q}_{fuel}} \times 100 \tag{2}$$



Explanation:

P(Elc)(t)	: electricity load at a given time.
Q(Cl)(t)	: cooling load at a given time.
P(PD)(t)	: electricity generated by power generator at a given time.
Q(MPM)(t)	: cooling by mechanical chiller at a given time.
Q(MPA)(t)	: cooling by absorption chiller at a given time.
P(MPM)(t)	: power input needed by mechanical chiller at a given time.
P(Ht)(t)	: power input needed by electrical heater at a given time.

Fig. 11 Flowchart of the simulation of trigeneration system

The daily operational costs of the trigeneration system based on daily simulation results determine the annual operational needs by considering the average occupancy rate of the hotel for one year. The operating costs for a year are estimated using Eq. (3). Where KO_{al} is the annual operating costs of the system, KO_{dl} is the daily operating costs of the system, and h is the average occupant rate of the hotel (%). Eq. (3) is not used only to calculate the annual operating costs, such as fuel and clean water, but also the annual operating load, such as the chiller operating load and the amount of power generated by gas engine generator.

$$KO_{al} = KO_{dl} \times h \times 365 \quad (3)$$

Evaluation of annual *LCC* includes investment, operating, and maintenance costs by considering the time value of the money. The evaluation method refers to the methods applied to the trigeneration system and cogeneration system in previous papers [4–6]. Various related economic parameters are included in this evaluation. The equal investment costs for each system are excluded to make a simple analysis without reducing the initial aim to compare solutions or alternatives. Generally, the annual *LCC* can be estimated using Eq. (4). Where I_{annual} is the initial investment that annual payment including interest rate, O_{annual} is the fixed annual operating cost, M_{annual} is the annual maintenance cost including the spare parts replacement.

$$LCC = I_{annual} + O_{annual} + M_{annual} \quad (4)$$

The annual operating costs are divided into the operating cost for the fuel and electricity, the operating cost for workers to operate the system, and the operating cost for providing the makeup water. Operating and maintenance costs assumed are uniformly for the economic life to obtain the annual *LCC*. The initial investments are converted to the annual costs by taking a constant interest rate so the uniformity value for the economic life. The investment cost for a year is estimated using Eq. (5) by including the time value of the money, where *r* is an interest rate per year, *y* is the economic life (year), and $I_{initial}$ is the initial investment cost.

$$I_{annual} = \frac{r(1+r)^y}{r(1+r)^y - 1} I_{initial} \quad (5)$$

VI. RESULTS AND ANALYSIS

Based on the engineering model and data assumptions described previously, some evaluations were conducted to reveal the feasibility of the trigeneration system. Alternative trigeneration systems are proposed under recent technology and available specification in the commercial market. Tables 2 and 3 display the trigeneration and conventional configurations, respectively. Three alternative trigeneration systems are compared by varying the water heating system. Specifications of the components are obtained from the data from brochures and other studies [7–13].

Table 2. Trigeneration system configuration

No.	Component	System 1	System 2	System 3
1	Gas Engine Generator	3 units (2 operate, 1 standby) @802 kWe	3 units (2 operate, 1 standby) @802 kWe	3 units (2 operate, 1 standby) @802 kWe
2	Absorption Chiller	3 units (2 operate, 1 standby) @240 RT	3 units (2 operate, 1 standby) @240 RT	3 units (2 operate, 1 standby) @240 RT
3	Centrifugal Chiller	3 units (2 operate, 1 standby) @300 RT	3 units (2 operate, 1 standby) @200 RT	3 units (2 operate, 1 standby) @200 RT
4	Electrical Heater	1 unit operate 82 kW	-	-
5	Chiller-Heater		2 units (1 operate 150 RT, 1 standby 200 RT)	2 units (1 operate 150 RT, 1 standby 200 RT)
5	Cooling Tower			
	• Direct Contact			
	- Cooling Tower 1 (Absorption Chiller)	1 unit operate 500 RT	1 unit operate 500 RT	3 units (2 operate, 1 standby) @ 500 RT
	- Cooling Tower 2 (Centrifugal Chiller)	2 units operate 350 RT	2 units operate 250 RT	2 units operate 250 RT
	• Indirect Contact (Absorption Chiller)	2 units (1 operate, 1 standby) @ 500 RT	2 units (1 operate, 1 standby) @ 500 RT	-
6	Hot Water Storage Tank			
	• Tank 1 (Temp. 40°C)	11000 L	14000 L	-
	• Tank 2 (Temp. 55°C)	20000 L	13500 L	13000 L
7	Machine Building	376 m^2	441 m^2	441 m^2

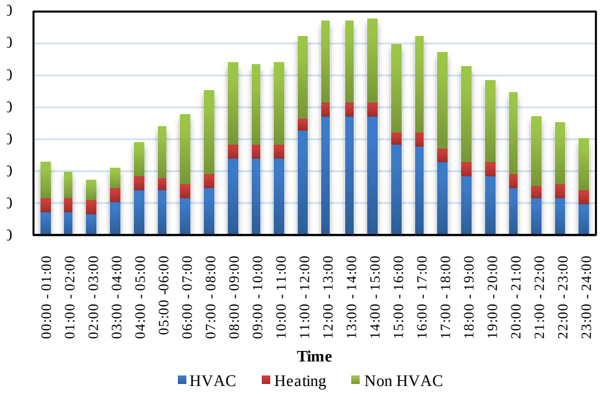
Based on the daily simulation results of the trigeneration system application on the hotel of the case study object, each alternative system has an electricity use profile that varies. The electricity usage profiles of each alternative trigeneration and the conventional system are shown in Fig. 12.

Figs. 12(a)–(d) show the electricity usage either trigeneration systems or conventional system dominated by the HVAC sector. The electricity usage by system 2 and system 3 is less than system 1, since their water heating systems do not require electrical power, but recovery of the waste heat from the chiller. While the water heating system of system 1 requires an electrical heater that needs quite large power input.

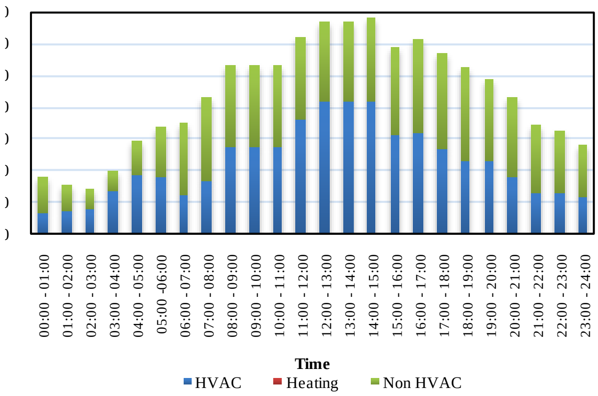
Overall, the electricity usage of the trigeneration systems is less than the conventional system. This condition is reasonable because the conventional system having the HVAC system still relies entirely on the mechanical chiller, and the water heating system with an electrical heater consumes a lot of electrical power input. In addition to the electricity usage, each alternative with a chiller usage profile varied. The chiller usage profile for each alternative trigeneration system is shown in Fig. 13.

Table 3. Conventional system configuration

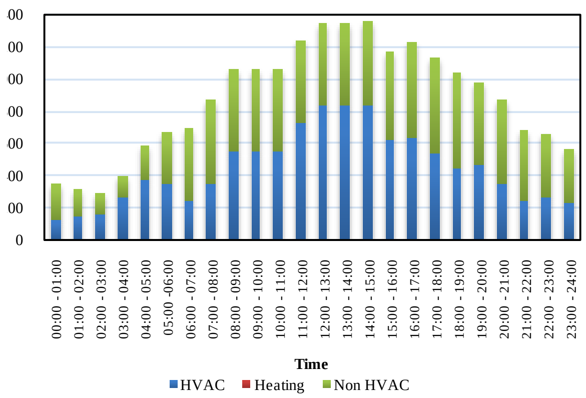
No.	Component	noitacificepS
1	Genset	2 units standby1000 kWe
2	Centrifugal Chiller	5 units (4 operate, 1 standby) @ 250 RT
3	Electrical Heater	1 unit operate 162 kW
4	Direct Contact Cooling Tower	5 units (4 operate, 1 standby) @ 300 RT
5	Hot Water Storage Tank	20000 L
6	Machine Building	305 m^2



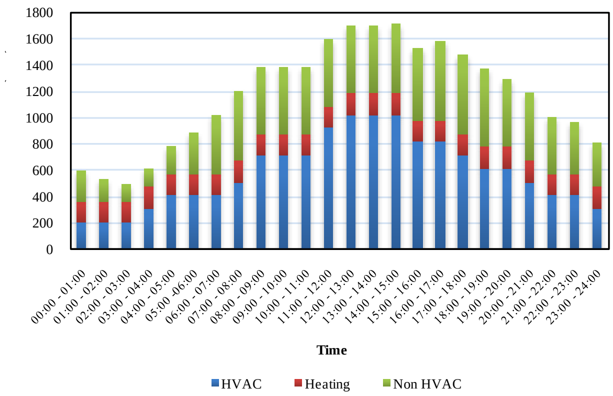
a) System 1



b) System 2



c) System 3

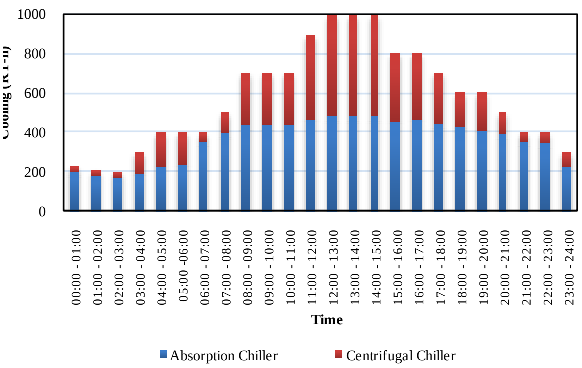


d) Conventional System

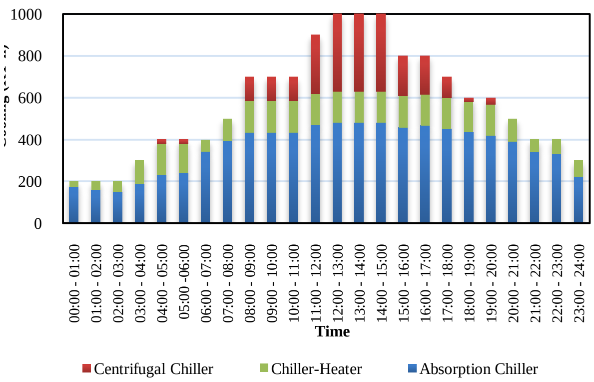
Fig. 12 The electricity usage profile

All proposed trigeneration systems use the absorption chiller to produce chilled water shown in Fig. 13. The chiller-heater on system 2 and system 3 are operated for a long day to ensure the continuity of the water heating process so that the centrifugal chiller is only running when the high cooling load is in the daytime.

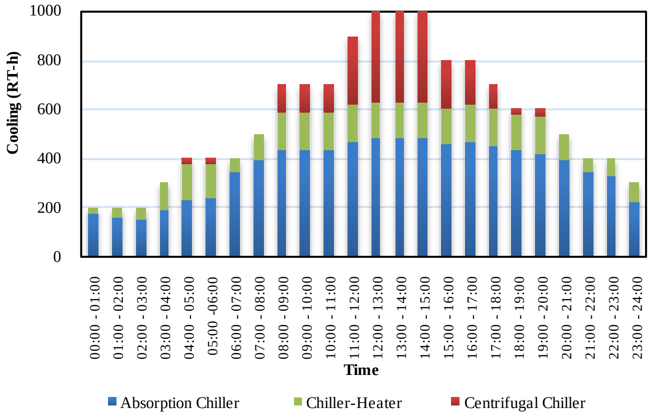
The different configurations of the HVAC system and water heating system cause the makeup water needs of the cooling tower to be different. The annual makeup water volumes for the cooling tower of each alternative system are shown in Fig. 14. The makeup water for the cooling tower of system 2 is the fewest due to the chiller-heater using the air coolant on system 2, so the cooling tower is not needed for the chiller-heater. In addition, system 2 utilizes the heat released by the absorber and condenser of one of the absorption chillers for the water heating system to save more water.



a) System 1



b) System 2



c) System 3

Fig. 13 The chiller use profile of trigeneration system

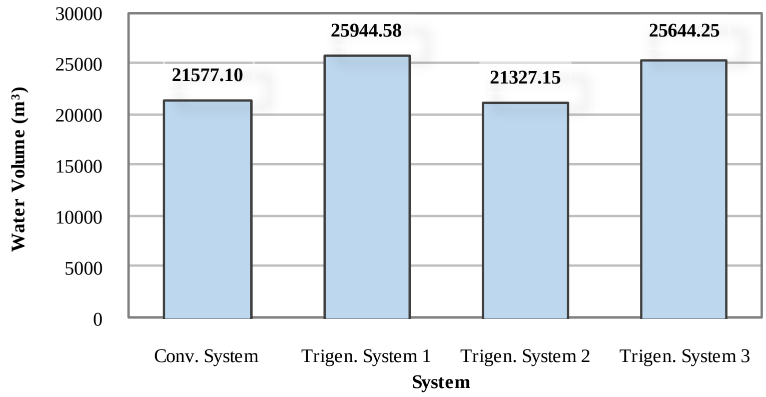


Fig. 14 The annual makeup water needs of cooling tower

Variations in the electricity usage of each trigeneration system impacted the natural gas fuel consumption so that required gas fuel quantities are different. Fig. 15 shows the annual natural gas fuel consumption for the proposed-trigeneration systems. The fuel consumption of system 1 is the highest, while system 3 is the lowest. It is a consequence of the electricity usage of system 1 being the highest, while system 3 is the lowest.

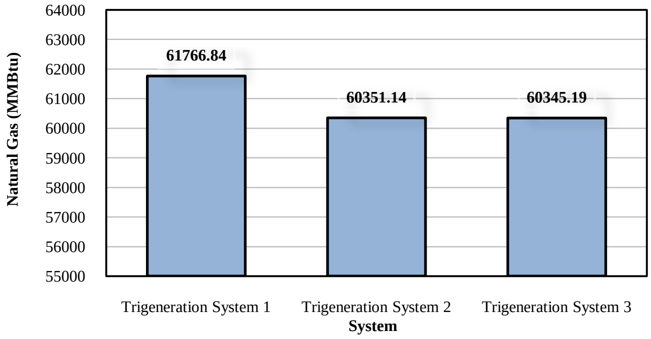


Fig. 15 The annual natural gas fuel needs

The electricity usage profile not only affects fuel consumption but also fuel utilization efficiency. Gas engine-generator operating with load variation for a long time causes the fuel utilization efficiency of the trigeneration system also changes. The fluctuation of daily fuel utilization efficiency for each proposed trigeneration system is indicated in Fig. 16. The fuel utilization efficiency is in the range of 86–88%. The daily fuel utilization efficiency profile of each system varies due to their operation condition since the gas engine generator is different. The curve of daily fuel utilization efficiency of system 2 and system 3 coincides since the operation load of each gas engine generator are almost similar and insignificantly different.

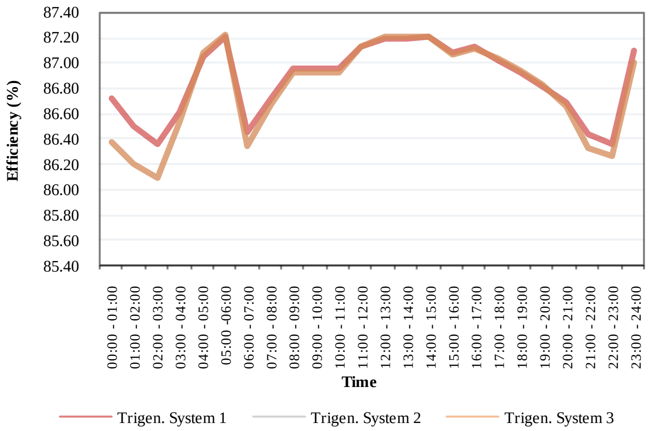


Fig. 16 The change of daily fuel utilization efficiency

As described previously, the annual *LCC* plays an essential role in revealing the feasibility of the trigeneration systems. Table 4 presents the annual *LCC* of the trigeneration and conventional systems. The annual *LCC* of the conventional system is higher than the trigeneration systems. The electricity cost dominates the annual *LCC* of the conventional system since it to be an energy source in the system. The electricity cost has the highest percentage of 75.36% and then followed by the investment cost of 19.78%, while the percentage of other costs is much lower than the electricity cost. Most investment costs of the conventional system are the procurement cost for the generator and HVAC system, such as the chiller and cooling tower. The annual *LCC* profile of the conventional system and the other three systems are quantitatively shown in Fig. 17.

The annual *LCC* of the trigeneration system is dominated by natural gas fuel cost, which is the energy source. Most of the annual *LCC* of the trigeneration system is not only for natural gas fuel costs but also investment costs. In contrast to the conventional system the percentage difference between energy source and investment costs in a trigeneration system is not too high. While the percentage of other costs, such as operation, maintenance, and water treatment, is lower than natural gas fuel and investment costs. Most of the investment costs in the trigeneration system are the procurement cost for the gas engine generator and HVAC system components. The annual *LCC* profile of system 1 is shown in Fig. 17(a). The annual *LCC* profile of systems 2 and 3 are not so far from system 1 as shown in Figs. 17(b) and (c). Only the percentage of the investment cost of systems 2 and 3 is slightly lower than system 1.

Table 4.The annual LCC of trigeneration system and conventional system

Cost Item	System (US$)			
	Conventional	Trigeneration 1	Trigeneration 2	Trigeneration 3
Investment of Gas Engine Generator	0	146,447	146,447	146,447
Investment of Genset	126,604	0	0	0
Investment of Absorption Chiller	0	77,131	77,131	77,131
Investment of Mechanical of Chiller	63,911	46,016	36,180	36,180
Investment of Cooling tower	34,329	56,680	52,103	45,772
Investment of Electrical heater	971	419	0	0
Investment of Hot Water Storage Tank	4,785	7,417	6,580	3,350
Fuel Consumption	0	436,692	426,683	426,640
OM Gas engine generator (exclude fuel)	0	64,389	62,789	62,783
OM HVAC system (Exclude electric/fuel)	22,039	27,134	26,977	26,977
Water (For makeup water cooling tower)	23,016	27,674	22,749	27,354
Building (Machine room)	8,944	13,086	15,348	15,348
Electricity	878,805	0	0	0
Total Annual *LCC*	1,166,121	903,085	872,986	867,982

System 3 is the most economical trigeneration system having lower annual *LCC* than other systems. It is due to the investment cost of the water heating system and the fuel cost of system 3 being the lowest. The water heating system of system 3 does not require an electrical heater and an indirect-contact cooling tower which is relatively more expensive than a direct-contact cooling tower. The water heating process of system 3 only requires one unit of hot water storage tank so it is superior to other systems requiring two hot water storage tanks.

Electricity and natural gas prices are varied in simulation to reveal the superiority between the conventional and trigeneration systems. The variation in electricity and natural gas prices is presented in Table 5. Fig. 18 shows the results of annual *LCC* for variation of the electricity price of conventional system and natural gas price for trigeneration system. The result shows the superiority of the trigeneration systems over the conventional system in terms of economics to the change in electricity and natural gas prices.

Table 5.The variation of electricity price and natural gas price

Variation	Electricity price(US$)	Natural gas price(US$)
1	0.063	7
2	0.074	7
3	0.100	7
4	0.100	11
5	0.100	13

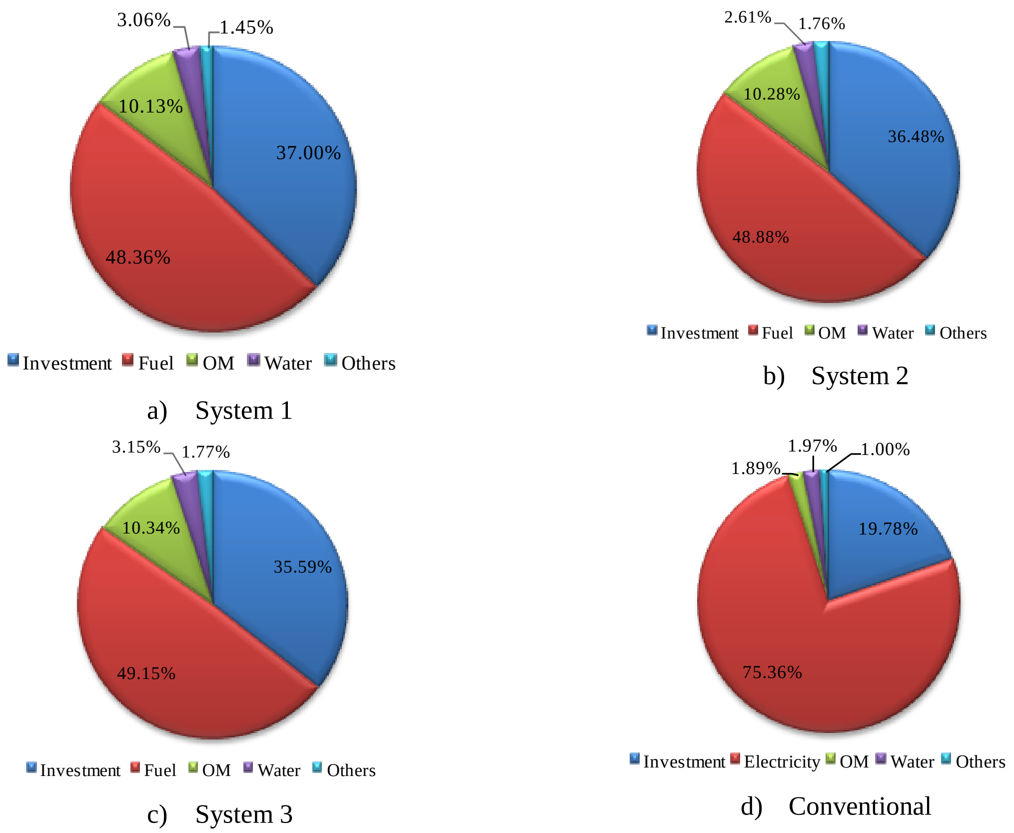


Fig. 17 Percentage of the annual *LCC* profile

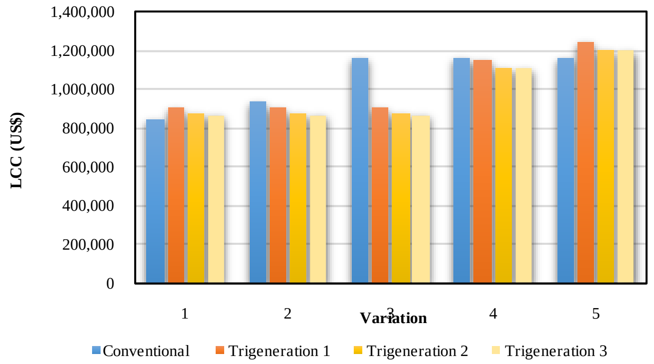


Fig. 18 The comparison of the annual *LCC* to the change of electricity price and natural gas price

For the Indonesian electricity price of about US$ 0.1 and industrial natural gas price of about US$ 7, the annual *LCC* of all proposed trigeneration systems is lower than the conventional system. If the electricity price decreased to US$ 0.074 at the same natural gas price, the annual *LCC* of the conventional system is still higher than all the trigeneration systems. Whereas if the electricity price decreased to US$ 0.063 and the natural gas price is fixed, then the annual *LCC* of the conventional system is lower than all the trigeneration systems. Supposing the natural gas price increases to US$ 11, and the electricity price fixes, then the annual *LCC* of the conventional system is still higher than all the trigeneration systems. Whereas if natural gas prices increase to US$ 13 and the electricity price fixes, the annual *LCC* of the conventional system is lower than all the trigeneration systems. Therefore, during the electricity price decreases and the natural gas price increases are not extreme, the trigeneration system is vastly superior to the conventional system from an economic aspect. Higher economic profit is prospective to be realized by changing the conventional system to a trigeneration system.

VII. CONCLUSION

Referring to the results and discussion of this study, some important conclusions can be drawn. The comparison between the conventional energy system and trigeneration system by using a hotel as an object of the case study was conducted by including energy conservation, and technical and economic aspects. Three alternative trigeneration systems were developed for a hotel. The gas engine was chosen as the prime mover in the power generating system and a variation of the water heating system was introduced.

The electricity usage of the trigeneration system is lower than the conventional system, which the alternative trigeneration system uses only a chiller-heater for the water heater (system 3) is the alternative system in which the electricity usage is the lowest. The decrease in the electricity usage of the trigeneration system compared to the conventional system cannot be separated from energy savings on the HVAC system by using an absorption chiller and water heating system by utilizing the heat released by the chiller. The trigeneration system using the combination of the utilization of heat released by the absorption chiller and chiller-heater for the water heater (system 2) is the alternative system using the lowest makeup water of the cooling tower.

The annual *LCC* of all alternative trigeneration systems is lower than the conventional system. The annual *LCC* of the trigeneration system is dominated by natural gas fuel cost, while the conventional system is dominated by electricity cost. The alternative trigeneration system that uses only a chiller-heater for the water heater (system 3) is the most energy-efficient and economical. The fuel consumption and annual *LCC* of system 3 are 60345.19 MMBtu/year and US$867,982, respectively, and it is lower than the other systems.

REFERENCES

[1] Shelar, M.and Kulkarni, G. N. [2016[, "Thermodynamic and Economic Analysis of Diesel Engine Based Trigeneration Systems for an Indian Hotel", Sustainable Energy Technologies and Assessments, Vol.13, pp.60–67.

[2] Zhao, X., Fu, L., Li, F. and Liu, H.[2014], "Design and Operation of a Tri-generation System for a Station in China", Energy Conversion and Management, Vol. 80, pp.391–397.

[3] Chen, Y., Zhang, T., Yang,H. and J. Peng, J. [2016], "Study on Energy and Economic Benefits of Converting a Combined Heating and Power System to a Tri-generation System for Sewage Treatment Plants in Subtropical Area", Applied Thermal Engineering, Vol. 94, pp.24–39.

[4] Astina, I.M. [2015],"Challenging of Trigeneration Plant for Commercial Building in Indonesia", Proceeding of 3rd Regional Conference on Energy Engineering and 7th International Conference on Termofluids, Yogyakarta.

[5] Astina, I.M. and Hariyanto, A. [2015], "Kajian Kelayakan Sistem Kogenerasi Turbin Gas Bandara Udara", Proceeding of KNEP VI, Bali.

[6] Astina, I.M. andHariyanto, A. [2015], "Studi Kelayakan Pembangkitan Daya Kogenerasi Mesin Gas Bandara Udara", Proceeding of SNTTM XIV, Banjarmasin

[7] Taufan, I.A. [2016], "Studi Kelayakan Sistem Trigenerasi pada Hotel di Indonesia", Final Project, Mechanical Engineering, FTMD ITB, Bandung.

[8] Underwood, C., Ng, B.and Yik F. [2015], "Scheduling of Multiple Chillers in Trigeneration Plants", Energies, Vol. 8, pp.11095–11119.

[9] "GE Power & Water Distributed Power", Jenbacher type 3, brochure.

[10] Trigenie, "Multi-energy Vapour Absorption Machines", Thermax, (http://www.thermaxglobal.com/pdf/Exhaust-Driven.pdf) (17 Feb 2016)

[11] "MHI Centrifugal Chiller Catalog", (https://www.mhi-global.com/products/ detail/centrifugal_chiller_web_catalog.html) (20 February 2016)

[12] "Heat Recovery from Air-Cooled Chillers", Carrier, 2009, (http://dms.hvacpartners.com/docs/1001/Public/03/04-581041-01.pdf)(14 Mar 2016)

[13] "Liang Chi Cooling Tower Catalog", (http://www.liangchict.com/images/ products/pdf/CTI%20Certified%20C-LC%20Series.pdf,)(07 Apr 2016)