

Economic Investigation of Small Scale Cogeneration System in a School Dormitory

**Boncheol Ku¹, Yulho Kang², Youngcheol Han³ Jaedo Song⁴
and Jaekeun Lee⁵**

^{1,2,3,4}Ph.D. Student, School of Mechanical Engineering, Pusan National University, San 30, Jangjeon 2 Dong, Geumjeong Gu, Busan 609-735, Korea,
Tel: +82-51-5103085, kalbc@pusan.ac.kr

⁵Professor, School of Mechanical Engineering, Pusan National University, San 30, Jangjeon 2 Dong, Geumjeong Gu, Busan 609-735, Korea,
Tel: +82-51-5102455, jklee@pusan.ac.kr

ABSTRACT: The cogeneration system can operate at efficiencies greater than those achieved when heat and power are produced in separate. The optimal system can be determined by selecting the auxiliary system combined with cogeneration system. In the present study, economic investigation has been conducted with the cogeneration electric heat pump (EHP) system and the cogeneration absorption chiller (AC) system to install in the school dormitory. To analyze life cycle cost (LCC), cost items such as initial investment costs, annual energy costs and maintenance costs of each system has been considered. The initial investment cost is referred from the basis of estimated costs, and annual energy costs such as the electric power and gas consumption are based on the data in a school dormitory. LCC is evaluated with the present worth method. Considering investigated results, the initial investment cost of the cogeneration EHP system is more profitable about 28% than the cogeneration AC system. The energy cost of the cogeneration EHP system is more profitable about 8% than the cogeneration AC system. The LCA shows that the cogeneration EHP system is most effective system in the school dormitory.

Keywords: LCC, Cogeneration, EHP, Absorption Chiller, Dormitory

NOMENCLATURE

- A Regular term-end payment for n year [US\$]
- e Escalation rate [%]
- F Term-end payment after n year [US\$]
- I Discount rate (interest rate) [%]
- P Present worth [US\$]
- n Expected life [yr]

1. INTRODUCTION

The Energy dependency of the Korea is very high. The Korea will have also accepted the obligations of the Kyoto protocol to decrease greenhouse gas emissions

[1]. So the energy efficiency of industrial plants and the school must be increased.

The gas demand by heating and the power demand by cooling are biased according to the season. If we adjust the seasonal energy balance, the energy demand is reduced. In order to adjust the seasonal energy balance and achieve more high energy efficiency, the cogeneration system is becoming a key issue.

The cogeneration system that produces electrical and heat energy from a single source of fuel is very efficient system with an efficiency of 85~90% in comparison to conventional thermal power plant between 30% and 40% [2, 3, 4]. The expected number of the cogeneration installations will be very high in the near future.

In many case, the installation of the cogeneration is connected to the other energy system for the efficiency. The optimal system can be determined by selecting the auxiliary system combined with the cogeneration system. The optimal efficiency can be determined by selecting the cogeneration system and the other energy system based on the annual demands of electricity and gas [5].

The cogeneration system combined with EHP system is more economical than the boiler system with electric heater or gas engine driven heat pump or boiler system connected with electric power grid by LCC analysis in the school dormitory [6, 7, and 8].

Recovery heat and power by the cogeneration system drives the cooling system with absorption chiller, it leads the

possibility of reducing the maximum power demand of the summer season at the hotel [9]. There were few reports that compare EHP and AC combined with the cogeneration system in the school dormitory. In the present study, we compare the EHP and AC combined with the cogeneration system to select more effective system for the school dormitory. Based on the energy demand data for electricity and heat, an optimal configuration of the cogeneration system at the school dormitory is determined by economic investigation.

2. DESIGN OF THE COGENERATION EHP AND AC SYSTEM

2.1 Heat load at the school dormitory

Table 1 shows heat load calculated from the school dormitory. The validity areas of the cooling and heating are 18,587 m². The load of cooling, heating and hot water is 2,803 kW, 2,750 kW and 1,070 kW.

2.2 Design of the cogeneration EHP system

Fig. 1 is the block diagram of the cogeneration EHP system. Power from the cogeneration system operates EHP for cooling and heating, the surplus heat which subtracts hot water demand from the cogeneration system radiates from radiator to air. When more heat is required than that can be supplied from the cogeneration

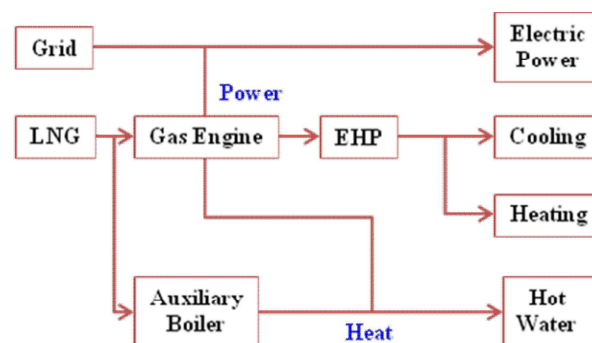


Figure 1: Block diagram of the cogeneration EHP system.

Table 1: Heat load at the school dormitory.

Dormitory	Space (m ²)	Cooling (kW)	Heating (kW)	Hot Water (kW)
L	4,885	835	782	12
M	7,423	1,036	1,036	573
W	4,682	653	653	350
S	1,997	279	279	135
Total	18,587	2,803	2,750	1,070

Table 2: Specification of the cogeneration EHP system.

System		Heat	Power
EHP (Out-door)	87kW*27 58kW*8 (2,813kW)	Cooling (kW)	
		2,813	922
		Heating (kW)	
		3,163	873
Cogeneration	30kW*35 20kW*8 (930kW)	Power and Heat (kW)	
		1,345	930

Table 3: Specification of the cogeneration AC system.

System		Power	Heat
AC	730RT*1 (2,819kW)	Cooling (kW)	
		230	2,213
		Heating (kW)	
		230	2,678
Aux. Boiler	4,250kW*1		3,820
Cogeneration	1,530kW*1	Power and Heat (kW)	
		Saving power	Recovery Heat
		1,300	2,219

system, auxiliary boiler can supply heat to an undersupply site.

Table 2 shows the specification of the cogeneration EHP system based on the heat load presented from Table 1.

EHP configuration shows that the outdoor system is 87 kW*27 sets and 58 kW*8 sets, the cogeneration system is designed as 930 kW*1 sets. The capacity of the cooling and heating are 2,813 kW and 3,163 kW, respectively. The power capacity of the cogeneration system is 930 kW, the recovery heat of the cooling is 1,345kW.

2.3 Design of the cogeneration AC system

Fig. 2 is the block diagram of the cogeneration AC system. Heat produced by gas engine supplies to AC for cooling. The heat from the auxiliary boiler supplies heating and hot water demand. The saving power which subtracts AC auxiliary device power from the cogeneration supplies other

building power demand in the school; it is the saving electric power.

Table 3 shows the specification of the cogeneration AC system based on the heat load presented from Table 1.

AC configuration shows that AC system is 730 RT (2,819 kW) which designed capacity to match recovery heat of the cogeneration system, the cogeneration system is 1,530 kW. The capacity of the cooling and heating are 2,819 kW and 2,434 kW, respectively. The power capacity, the recovery heat and the saving power of the cogeneration system are 1,530 kW, 2,219 kW and 1,300 kW, respectively.

3. ECONOMIC ANALYSIS OF THE COGENERATION EHP AND AC SYSTEM

3.1 Method of LCC analysis

The definition of LCC is the total expense which sums generally the each expense

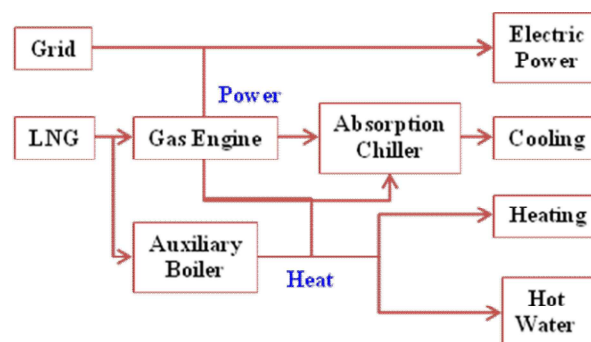
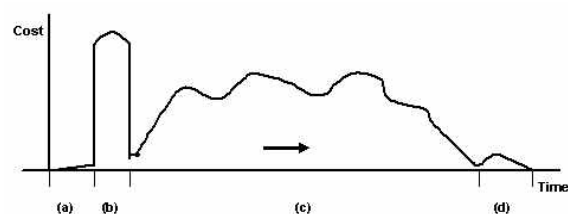
**Figure 2:** Block diagram of the cogeneration AC system.**Figure 3:** Occurrence time of the general LCC in each cost breakdown structure. (a) Plan & design; (b) Initial investment and Support; (c) Energy and Maintenance; (d) Scrapping of equipment

Table 4: Initial cost of each system.

Item	Cogeneration		
	EHP	AC	EHP -AC
Cogen. Total	1,334,000	2,218,000	
EHP or AC	1,036,000	695,000	
Construction & control	817,000	1,181,000	
Total (US\$)	3,187,000	4,094,000	907,000

from production, use and disposal of the products.

Fig. 3 shows an occurrence time of the general LCC in the cost breakdown structure. Initial investment, support and energy cost are important factors. Generally, if the initial investment cost is high and energy cost is low, it will be able to shorten a pay-back period by assisting government subsidies initially.

The air conditioning system is analyzed by present worth method because annual cost is regularly occurring open. In the present worth method, cost is already present value like initial investment costs and costs occurred in future are exchanged present value [9, 10].

Escalating annual costs are changed to present cost using Equation (1). Unchanging annual costs are changed to present cost using Equation (2). Costs only occurred 1 time during a few years are changed to present cost using equation (3).

$$P = A \times \frac{\left(\frac{1+e}{1+i}\right) \cdot \left(\left(\frac{1+e}{1+i}\right)^n - 1\right)}{\left(\frac{1+e}{1+i}\right) - 1} \quad (1)$$

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n} \quad (2)$$

$$P = F \times \frac{1}{(1+i)^n} \quad (3)$$

LCC analysis sets that there is interest 8%, escalating power rates 4%, escalating LNG cost rates 2%, operating time 20year.

The cogeneration GHP system has several advantages as financial aid by government. It is low interest. Total initial investment cost of the cogeneration EHP systems is loaned inside 100% and interest only is paid for 3 years from initial time and initial investment cost is refunded to be divided for 5 years when interest rate is 2.25% to floating after 3 years. But it is difficult to predict fluctuating interest, and so the interest is assumed fixed interest 2.5% in this study.

3.2 Initial investment cost

Table 4 shows estimates of initial investment cost from the professional company. Total cost of the cogeneration system which receives the support cost is calculated separately to analyze LCC.

The initial investment costs of the cogeneration EHP system and the cogeneration AC system are \$3,187,000 and \$4,094,000, respectively. The cogeneration EHP system is cheaper about 28% than the cogeneration AC system.

The cogeneration capacity of the cogeneration EHP and Cogeneration AC matches the power demand of the EHP and gas demand of the AC which needs rich gas, respectively, and so Cogeneration AC cost expensive relatively. The EHP of the cogeneration EHP is the expensive products itself relatively. The construction and control cost of the cogeneration AC has much pipe work cost and auxiliary parts such as cooling tower, pump, etc.

3.3 Energy Cost

Table 5 shows the energy costs of each system. The energy costs of the cogeneration EHP system and the cogeneration AC system are \$210,100 and \$230,200 which included saving power cost produced from the cogeneration system of the cogeneration AC system, respectively. Finally, the cogeneration EHP system is cheaper about 8% than the cogeneration AC system.

Table 5: Energy cost of each system.

Item	Cogeneration		
	EHP	AC	EHP-AC
Cooling	106,600	134,600	
Heating	80,800	216,000	
Hot Water	22,600	83,300	
Saving Power		-206,700	
Total (US\$)	210,100	227,200	17,100

Table 6 : Electricity charge for education (choice II high voltage A, Nov., 2005)

Basic Charge (US\$/kW)	Power demand charge (US\$/kWh)		
	Jul.~Aug.	Apr.~Jun. Sep	Oct.~Mar.
5.87	0.0818	0.0513	0.0557

Table 7: LNG price (US\$/m³, Nov., 2005)

Busan	Cogeneration	0.4616
	Central heating	0.55552

Table 8: Gas consumption

Cogeneration (Nm ³ /h, kW)	0.3
AC (Nm ³ /h, 100RT)	27.3

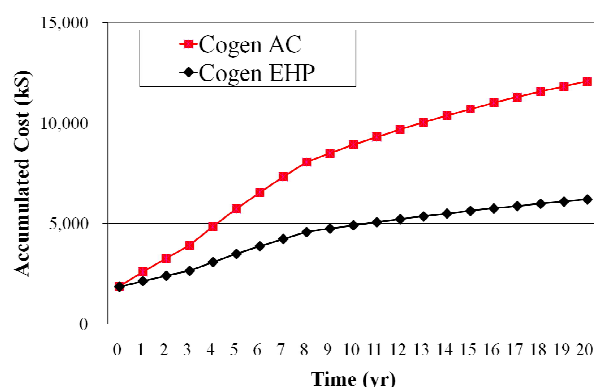
Table 9: Total cost (initial & energy) of each system.

Item	Cost (US\$)		
	Cogeneration		
	EHP	AC	EHP-AC
Initial	3,187,000	4,094,000	907,000
Energy	210,000	227,000	17,000
Total	3,397,000	4,321,000	924,000
Ratio			
Initial	1	1.28	
Energy	1	1.08	

The cogeneration AC has low COP and need auxiliary boiler to meet hot water demand. It needs much gas and little power.

The surplus power lower the total cost of the cogeneration AC.

The basic data which is necessary to an analysis make reference as below. The data is quoted the reference from relation

**Figure 4:** LCC analysis of each system.

standards and company information [11, 12]. The lower heating value of liquefied natural gas (LNG) of 9,550 kcal/Nm³, Auxiliary boiler efficiency of 90% and operating rate for hot water of 0.6 is used.

Table 6, Table 7 and Table 8 shows electricity charge for education, LNG price and gas consumption, respectively.

Table 9 shows total costs of each system, which sum initial investment and energy cost of systems. The cogeneration EHP system and the cogeneration AC system are \$4,152,000 and \$5,326,000, respectively. The cogeneration EHP system is cheaper about as 27% than the cogeneration AC system

3.4 Result of the LCC analysis

Fig. 4 is simplified LCC analysis of the each system. Because the cogeneration EHP system is lower than the cogeneration AC system at the initial investment cost, the cogeneration EHP system has comparative advantage than the cogeneration AC system from an early year.

4. CONCLUSION

Economic investigation is conducted with the cogeneration EHP system and the cogeneration AC system to install in the school dormitory. By comparing the result of the two systems, we come to the following conclusion.

In the case of the initial investment cost, the cost of the cogeneration EHP system and the cogeneration AC system are \$3,187,000 and 4,094,000, respectively. The cogeneration EHP system is cheaper about 28% than the cogeneration AC system.

In the case of the energy cost, the cost of the cogeneration EHP system and the cogeneration AC system are \$210,100 and \$227,200, respectively. The cogeneration EHP system is cheaper about 8% than the cogeneration AC system.

The cogeneration AC system is high at the initial investment and energy cost, it has also low COP, and so we suggest that the cogeneration EHP system which has relatively comparison advantage to the school dormitory.

This year the cogeneration EHP system will be installed at the school dormitory. The next papers compared this LCC result with an actual data will be written.

ACKNOWLEDGEMENT

This work was supported by Korea Energy Management Corporation and Busan city, Korea. The authors gratefully acknowledge the financial support.

REFERENCES

- [1] Kyoto Protocol to the United Nations Framework Convention on Climate Change.
- [2] Baughn, J, Kerwin, R. 1987. Comparison of the predicted and Measured Thermodynamic Performance of a Gas Turbine Cogeneration System. ASME J Eng Gas Turbo Power. Vol 109. pp32-38.
- [3] Lundberg, M. 1991. Latent Heat Utilization in Steam-injected Gas Turbine Application. Proceeding ASME COGEN-TURBO. IGIT-6. pp9-18.
- [4] Rosen, M. 1998. Reduction in Energy Use and Environmental Emissions Achievable with Utility-based Cogeneration: Simplified illustrations for Ontario, Appl Energy. Vol 61. No 3. pp163-174.
- [5] Oh, S, Lee, H, Jung, J, Kwak, H. 2007. Optimal Planning and Economic Evaluation of Cogeneration System. Energy. Vol 32. pp760-771.
- [6] Kong, D, Lee, K, Kim, I, Kim, C. 2007. Economic Analysis of a Cogeneration System Combined with an EHP. Proceeding of the KSME 2007 Winter Annual Conference. pp1548-1553.
- [7] Shin G, Kim, G, Joo, H, Lee, J. 2006. Economic Analysis of Heat Pump System through Actual Operation. Proceeding of the SAREK 2006 Summer Annual Conference. pp 921-926.
- [8] Park, C, Kim, Y. 1997. An Economic Assessment of Co-generation System. Proceeding of the SAREK 2006 Summer Annual Conference. pp 613-620.
- [9] Leigh, S. 2000. Optimization of Facility Management based on a Life-cycle Cost Analysis. Journal of Korea Facility Management Association. Vol 2., No. 1. pp 79-90.
- [10] Dhillon, B. 1989. Life Cycle Costing Techniques. Models and Application. pp 8-26.
- [11] Korea Gas Corporation, 2005. 11, "Natural Gas Fee"
- [12] Korea Electric Power Corporation, 2005.11, "Electric power fee"