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Techno-Economic Viability of Cogeneration in a Commercial Building in Bangladesh

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Abstract

An investigation regarding the cogeneration potential in a typical commercial building in Bangladesh was carried out. Information on steam and electricity consumption in the commercial building was collected through site visits and surveys via questionnaire. Historical energy consumption data shows that the power to heat ratio of the plant was 0.23. For average power to heat ratio of 0.23, three types of the prime movers i.e. steam turbine, reciprocating engine and gas turbine cogeneration system were considered. From the sensitivity analysis the potential cogeneration alternatives (assuming vapour compression chillers) of the commercial building, the reciprocating engine power match option meeting power requirement of 800 kW appears to be the most suitable co-generation system. It represents an initial investment of 35.6 billion Taka (1 US$ = Tk 48.5) and leads to an internal rate of return of 43.5%. By using vapour absorption cooling for the commercial building electricity demand may be reduced sharply.

Nomenclature

AF	Annuity factor
CHP	Combined heat power
CF	Cash flow for specific year
GTTM	Gas turbine thermal match
GTPM	Gas turbine power match
I	Investment
i	Discount rate
IRR	Internal rate of return
n	Economic life of the plant
NPV	Net present value
RETM	Reciprocating engine thermal match
REPM	Reciprocating engine power match
STTM	Steam turbine thermal match
STPM	Steam turbine power match
TR	Ton of refrigeration
VAC	Vapour absorption chillers
VCC	Vapour compression chillers

Introduction

Cogeneration is the simultaneous production of heat and electricity at, or close to, the point of use. It utilizes the heat that is inevitably produced in electricity generation from fuels to feed heating/cooling systems for buildings or directly in industrial process. By making use of this heat, which is lost in the conventional electricity only generation is the most efficient way of turning fuels into useful forms of energy [1].

Conventional generation of electricity in large central power stations is normally only 30-40% energy efficient. More recent combined cycle generation can improve this to 55%, excluding losses in the transmission of electricity, which can be as great as 30% or ever more of the delivered efficiency. Hence, conventional electricity only stations release large amounts of energy as waste heat, normally via large cooling towers or by cooling with sea or river water [2, 3].

Through the utilization of the heat, the efficiency of cogeneration plant can reach 90% or more. Cogeneration therefore offers energy savings ranging between 15% and 40% when compared with the supply of electricity and 40% when compared with the supply of electricity and heat from conventional power stations and boilers [4, 5].

Cogeneration (CHP) is now in minds of many policy makers, as a way both to improve competitiveness and to reduce our impact on the environment. Cogeneration is set to play a major role in post-Kyoto carbon reduction strategies around the world. As well as cutting energy costs for a wide range of users, cogeneration uses fuel at very high efficiencies to reduce emissions of both carbon dioxide and other pollutants associated with combustion [3, 6]. Provided the cogeneration is optimized in the way described above, the following benefits arise:

- Increased efficiency of energy conversion and use.
- Lower emissions to the environment, in particular of CO_2, the main greenhouse gas.
- Large cost savings, providing additional competitiveness for industrial and commercial users and offering affordable heat for domestic users.
- An opportunity to move towards more decentralized forms of electricity generation, where plant is designed to meet the needs of local consumers, providing high efficiency, avoiding transmission loses and increasing flexibility in system use. This will particularly be the case if natural gas is the energy carrier.
- Improved local and general security of supply-local generation, through cogeneration, can reduce the risk that consumers are left without supplies of electricity and/or heating. In addition, the reduced fuel need that cogeneration provides, reduces import dependency.
- An opportunity to increase the diversity of generation plant and provide competition in generation. Cogeneration provides one of the most important vehicles for promoting liberalization in energy markets.
- Increased employment-a number of studies have now concluded that the development of CHP systems is a generator of jobs.

Energy consumption of the hotel

The hotel operates throughout the year without any stop. Electrical energy is required for air conditioning, lighting, and pump motors whereas a lot of steam is used in various applications like kitchen, laundry etc. The energy consumption pattern of this hotel is shown in Fig. 1. From the Fig. 1 it is evident that 85% electrical energy is consumed by VCC.

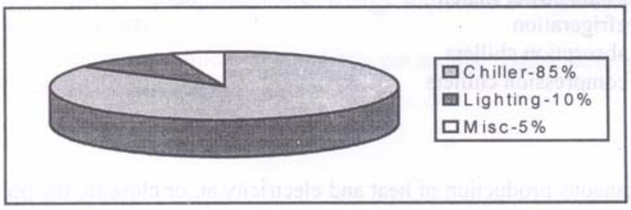

Fig. 1 Electric power consumption of the hotel

Electricity consumption

The monthly average electricity consumption for the year 1998 is shown in Fig. 2.

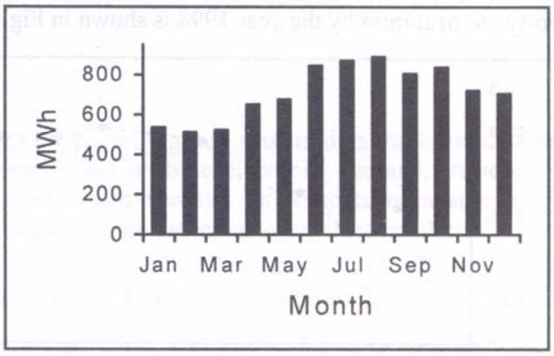

Fig. 2 Monthly average electricity consumption for the year 1998

Analysis of Fig. 2 shows that:

Maximum electricity consumption (Aug)	: 890 MWh
Minimum electricity consumption (Mar)	: 513 MWh
Maximum electricity demand	: 1000 kW
Minimum electricity demand	: 900 kW
Total electricity consumption	: 8580 MWh

Steam consumption

The monthly average steam consumption for the year 1998 is shown in Fig. 3.

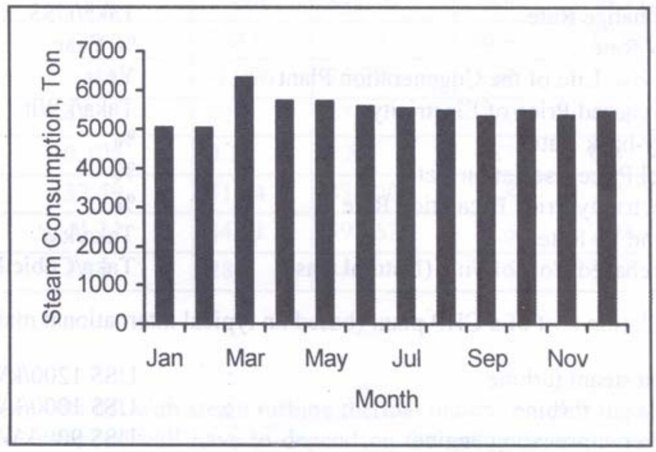

Fig. 3 Monthly average steam consumption for the year 1998

Analysis of Fig. 3 shows that:

Maximum steam consumption (Mar)	: 6317 Ton
Minimum steam consumption (Feb)	: 5033 Ton
Total steam consumption	: 60615 Ton

Power to heat ratio

The monthly average power to heat ratio by the year 1998 is shown in Fig. 4.

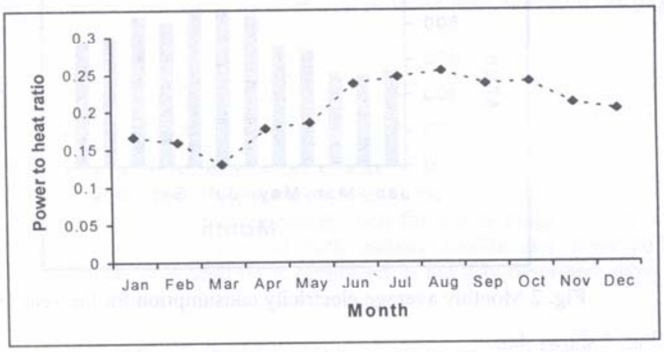

Fig. 4 Monthly average power to heat ratio for the year 1998

The average power-to-heat ratio of the site was calculated to be 0.23 for 1998. Typical cogeneration system suitable for this site would be based on steam turbine [1]. However, reciprocating engine and gas turbine cogeneration systems were also considered as potential alternatives.

Assumptions used in the study

Assumptions used in the study are as follows:

Exchange Rate	Taka/US$	48.5
Tax Rate	%/Year	35
Service Life of the Cogeneration Plant	Year	15
Purchased Price of Electricity	Taka/kWh	3.6
Buy-back Rate	%	80
Fuel Price Escalation Rate	%	5-13
Electricity Price Escalation Rate	%	6-13
Stand by Rate	Taka/kW	80
Purchased Cost of Fuel (Natural Gas)	Taka/Cubic Meter	3.65

Assumed installation cost of a CHP plant (based on typical international market price [1]):

For a steam turbine	:	US$ 1200/kW
For a gas turbine	:	US$ 1000/kW
For a reciprocating engine	:	US$ 900/kW

The net present value of cogeneration plant has been estimated as follows:

$$NPV = (CF)(AF)-(I)$$

$$AF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

The NPV estimates the gain or loss resulting from the proposed investment. Therefore, if NPV is positive, the investment should be made because the relevant revenues exceed the financing cost. If NPV is negative, the plant is not proposable.

Methodology

A spreadsheet developed by the ESCAP-UN study group was used as the basic data analysis tool, which was modified to meet the local requirements. Data on base electricity demand, steam demand, annual electricity consumption, annual thermal energy requirement were the initial inputs to the spreadsheet analysis. The related parameters required for cogeneration analysis were estimated using the spreadsheet.

Summary of the results obtained by using VCC as the cooling option

The steam turbine, reciprocating engine and gas turbine options with thermal match and power match results are shown in a computer print out of the spreadsheet analysis in table 1. The results in the table also show the internal rate of return on net investment for each option. Lastly three alternatives were considered for sensitivity analysis.

Table 1 Summary of the study of the hotel

Major Parameters	Steam Turbine		Gas Engine		Gas Turbine	
	Thermal Match	Power Match	Thermal Match	Power Match	Thermal Match	Power Match
Installed power (kW)	653	900	10,137	900	4,339	900
Fuel consumption (TJ/Yr)	230	317.5	1,001.5	88.9	520	107.9
Electricity generated (MWh)	5,400	7,490	84,376	7,490	36,112	7,490
Heat generated (TJ/yr)	184.6	254.6	184.6	16.4	184.6	38.3
Surplus/deficit(-) power (MWh/yr)	-3,149	-1,090	75,796	-1,090	27,532	-1,090
Surplus/deficit(-) heat (TJ/yr)	47	92.1	47.6	-120.6	47.6	-98.7
Equipment power-to-heat ratio	0.106	0.11	1.87	1.87	0.8	0.8
Total investment (million Taka)*	37.59	51.84	438.00	38.88	208.29	43.20
Net present value (million Taka)	41.11	44.61	597.67	78.61	249.30	74.83
IRR (%)	31.2	28	34.9	43.5	32.6	39.8

Discussions

The steam turbine option gave two results: (i) with steam turbine thermal match (STTM), less than 65% of the power requirement is generated and the hotel will have to depend on the utility grid; (ii) with steam turbine power match (STPM), only a small amount of excess heat is generated. [5, 6]

With the reciprocating engine thermal match (RETM) option, 900% excess power is generated. The project profitability will depend on the buy-back rate. This may not be a good option as the purpose is not to earn from electricity sale. Reciprocating engine power match (REPM) option seems good as almost all the power needed can be met though there will be small (15%) shortage in the heat supply. There is no need for an auxiliary boiler as this shortfall can be easily made up by auxiliary natural gas firing in the recovery boiler.

With gas turbine thermal match (GTTM) option, about 320% excess electricity is generated, which has to be sold as in the RETM option. Gas turbine power match (GTPM) option takes care of all the power needs though heat deficit is as high as 60%. This will require the adoption of auxiliary natural gas firing in the recovery boiler.

From the practical point of view of unreliability associated with the present power utility services of Bangladesh, the power match options were considered for further analysis. Accordingly, the sensitivity analysis carried out to see the impacts of the increase in the investment, fuel and electricity price escalation was limited to STPM, REPM and GTPM options.

Scope of the alternative cogeneration system

The above results of the hotel were obtained by assuming VCC. Cogeneration can provide power and cooling by incorporating VAC also. The cooling load demand of the hotel is 1500 TR which was achieved by driving a VCC. The required electricity demand of the hotel is 900 kW which is used to drive the VCC. On the other hand this cooling effect may be achieved by driving a VAC which will require electricity of 150 kW only [4].

Other studies have shown that a cogeneration system incorporating a typical VAC can save about 25% of primary energy in comparison with only power generation system with VCC [3]. Furthermore, a smaller prime mover leads to not only lower capital cost but also less standby charge during the system breakdown because steam needed for the chiller can still be generated by auxiliary firing of the waste heat boiler. Again, the proposed system is independent of national grid which is already overburden.

Sensitivity analysis

The sensitivity analysis of the studied commercial building is shown in Fig. 5, 6 and 7.

Fig. 5 shows that internal rate of return linearly decreases with increases of the investment cost for all alternatives. As the investment cost increases from 1% to 15%, IRR varies from 43.5% to 38.8% for REPM, 39.8% to 34.9% for GTPM and 28% to 24.89% for STPM.

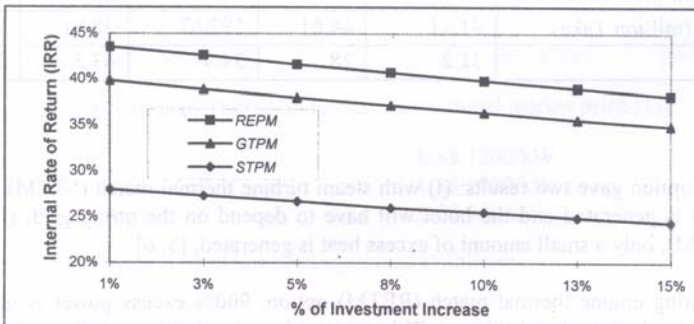

Fig. 5. Internal rate of return versus investment cost

Fig. 6 shows that internal rate of return linearly decreases with increases of the fuel price escalation rate for all alternatives. As the fuel price escalation rate increases from 5% to 13%, IRR varies from 43.5% to 38.8% for REPM, 39.8% to 34.9% for GTPM and 28% to 24.89% for STPM.

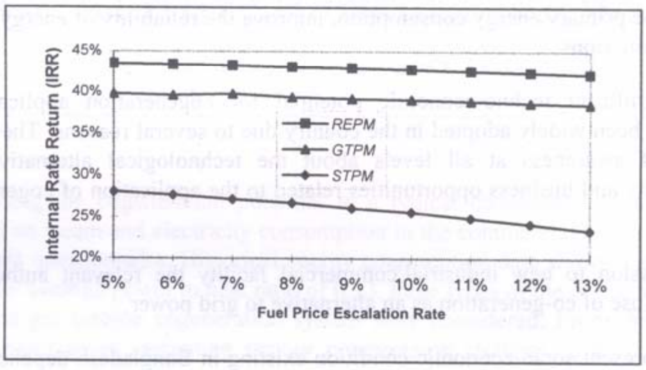

Fig. 6. Internal rate of return versus fuel price escalation rate

Fig. 7 shows that internal rate of return linearly increase with increase of the electricity price escalation rate for all alternatives. As the electricity price rate increases from 6% to 13%, IRR varies from 43.5% to 52.3% for REPM, 39.8% to 44.6% for GTPM and 28% to 34.7% for STPM. The increasing trend of the internal rate of return is found mainly due to the increasing revenues generated from the displaced electricity and from the selling of excess electricity.

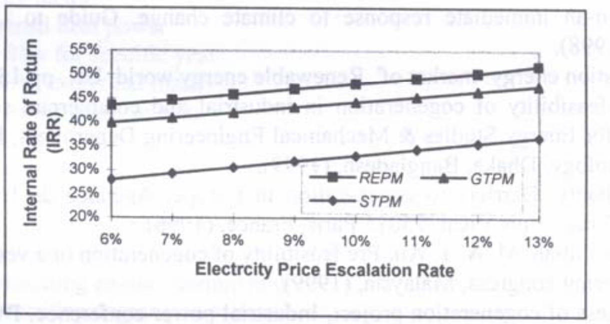

Fig. 7. Internal rate of return versus electricity price escalation rate

Conclusions

- The power demand of this hotel by assuming VCC as cooling option is 1000 kW which is not very high. This type of commercial building is always suitable for small-scale cogeneration with gas fired reciprocating engine which is available in the local market.

- From the sensitivity analysis of the potential cogeneration alternatives for the commercial building, the reciprocating engine power match option meeting power requirement of 800 kW is found to be the most suitable cogeneration system. It represents an initial investment of 35.6 Million Taka and leads to an internal rate of return of 43.5%.

- In the commercial buildings VAC need to be promoted. This will allow to increase the overall efficiency of energy use, reduce the primary energy consumption, improve the reliability of energy supply and reduce the global atmospheric emissions.

- In spite of the significant techno-economic potential for cogeneration applications in Bangladesh, cogeneration has not been widely adopted in the country due to several reasons. The foremost among them is the low level of awareness at all levels about the technological alternatives, economic merits, environmental benefits and business opportunities related to the application of cogeneration as an efficient energy use option.

- When giving permission to new industrial/commercial facility the relevant authority should give due considerations to the use of co-generation as an alternative to grid power.

- With respect to the present socio-economic condition existing in Bangladesh dependability for power with national utility may hamper the reliability of planned production and services. In this aspect self- captive generation in prospective cogeneration sites may improve reliability and efficiency as well as reducing the burden to already stressed national grid.

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