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Feasibility Study For Implementing Tri-Generation Systems In The Hotel Industry In Sri Lanka

For

Sri Lanka Sustainable Energy Authority,
Block 05, 1st Floor,
BMICH ,
Bauddhaloka Mawatha,
Colombo 07

By

LJ Energy Lanka Pvt Ltd

410/108B,
Bauddhaloka Mawatha,
Colombo 07

I. EXCECUTIVE SUMMARY

Tri-generation or Combined Heat, Power and Cooling refer to the simultaneous generation of electricity and useful heating and cooling from one source of energy. Eighty percent (80%) of the energy in the primary fuel can be utilized by tri-generation and is one of the best methods available for maximum utilization of energy.

Since hotels use electrical energy for air conditioning and thermal energy for generating hot water and steam, the hotel industry was identified as having potential for implementing tri-generation systems.

The feasibility study involved collecting data on the energy consumption profiles and other related information from hotels. The data was then analysed to establish typical electrical, thermal and cooling demand characteristics for hotels based on the number of guest rooms.

Data collected from hotels provide a good correlation between the hotel size (number of guest rooms) and the electrical power demand, heat (steam) demand and the cooling demand. It was also observed that the main heat demand in hotels is during the day time during laundry operations (on average about 12 hours per day). Therefore, tri-generation systems in hotels would effectively be able to operate only during the day time.

A study was also conducted to identify suitable technologies available for tri-generation in hotels. The study found that although many types of systems are available, due to factors such as the relatively low capacity requirements, ratio of heat to power demand and availability of fuels, only internal combustion engine based generators would be suitable for this application in the hotel industry.

In an internal combustion engine based tri-generation system, the waste heat from the exhaust could be used to generate steam (for the laundry and production of hot water) while the jacket cooling system can be used to produce hot water to operate absorption chillers for providing air conditioning.

A financial analysis was conducted to study the economic viability of using tri-generation for hotels. Analysis conducted using the present cost of electricity and fuel indicate that it would not be viable because the cost of generating steam and electricity from such a system would be higher than the current cost of steam generation using boilers and purchase of electricity from the grid.

The two main reasons why tri-generation is not currently viable for the hotel industry are:

1) Currently, steam is generated in boilers using furnace oil which is about 15% cheaper than diesel that is generally required to operate electrical power generators
2) Grid electricity tariff is approximately 30% of the cost of electricity generation using generators.

However, if the cost of electricity rises relative to the cost of fuel in the future, tri-generation system may become financially viable. Therefore, further analysis was

conducted to identify the conditions under which tri-generation could become financially viable for the hotel industry.

A sensitivity analysis conducted for varying fuel and electricity cost shows that tri-generation would become financially viable in the future under the following scenario (based on simple payback period of not more than 10 years):

- Not feasible in general for hotels with 200 or less guest rooms even if the fuel or electricity cost varies by as much as 20%
- Feasible for hotels with 250 to 300 rooms if fuel price reduces by 20%
- Feasible for hotels with more than 300 rooms if fuel price reduces by 20% or if electricity tariff increases by 20% or a combination of a minimum reduction in fuel cost of 10% and electricity tariff increase of 10%.

Therefore, it is recommended that if fuel and electricity costs vary in the future such that any of the above criteria are met, then hotels should consider implementing tri-generation systems.

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1.0 INTRODUCTION

1.1 Background

Tri-generation or Combined Heat, Power and Cooling refer to the simultaneous generation of electricity and useful heating and cooling from one source of energy. Eighty percent (80%) of the energy in the primary fuel can be utilized by tri-generation. This is one of the best methods available for maximum utilization of energy.

Figure 1.1 shows the difference in efficiency between the conventional method of individually generating electricity and heat (steam) separately with a combined system.

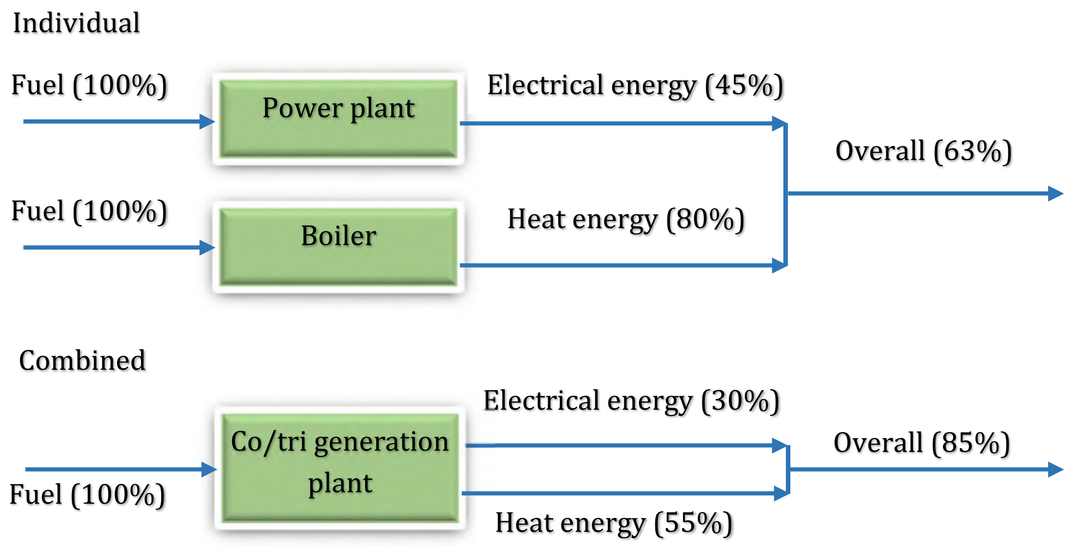

Figure 1.1 Comparison of efficiency

Since Hotels use electrical energy for air conditioning and other systems while generating steam for laundry activities as well as producing hot water, the Hotel industry has been identified as one of the sectors which has potential for implementing tri-generation systems. Therefore, Sri Lanka Sustainable Energy Authority engaged LJ Energy Lanka Pvt Ltd to carry out a feasibility study on this subject.

1.2 Objective of the Study

The main objective of this study was to assess the feasibility of implementing tri-generation systems in the Sri Lankan hotel industry.

In order to achieve this, a detailed methodology was developed to collect and analyse operational data from selected hotels. Some of the key parameters collected from the hotels included the overall electricity consumption, fuel usage and cooling requirements.

1.3 What is Tri-generation

Tri-generation is the combined generation of electricity, heat and cooling, all simultaneously produced from a single fuel source. It is also often referred to as Combined Heat Power and Cooling (CHPC). Tri-generation can be considered as an extension of cogeneration where waste heat is also utilised for producing cooling.

Figure 1.2 illustrates the main components of a tri-generation system which consists of a conventional power generation system (engine, gas turbine or steam turbine) together with a waste heat recovery system for steam generation and an absorption chiller for generating chilled water.

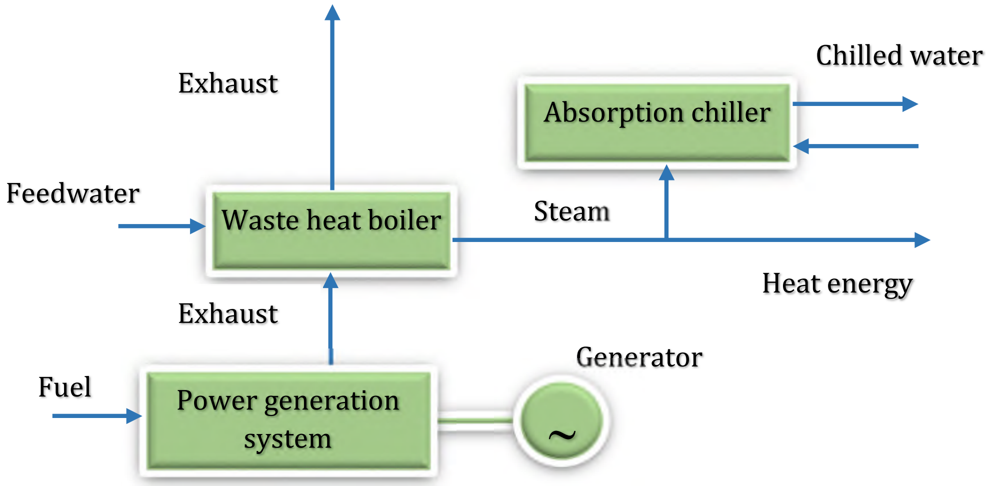

Figure 1.2 Typical arrangement of a tri-generation system

2.0 AVAILABLE TECHNOLOGY

There are many technologies available in the market for combined heat and power generation. They can generally be classified as large, medium and small size systems based on their electrical power and heat output.

- Large size systems – Steam turbine and combustion turbine (>1 MW)
- Medium size systems – Internal combustion engine (0.25 – 10 MW)
- Small size systems – Microturbines (<250 kW)

A description of each type of system is provided below.

2.1 Steam Turbine

The steam turbine power generation cycle has been backbone of the power generation industry. There are three major components in a steam turbine power generation system which are the heat source (boiler which produces superheated steam), the turbine itself and a heat sink. The steam turbines are also categorized based on the exit steam conditions as either a backpressure or condensing steam turbine system.

2.1.1 Back Pressure Turbine

In a back pressure steam turbine (Figure 2.1), the superheated steam produced by a boiler is supplied to a turbine where part of its energy is extracted to produce work and in the process, reducing the pressure of the steam. The low pressure steam available at the outlet of the turbine is then used for heating applications including the operation of absorption chillers for cooling. The condensate is usually recovered and returned back to the boiler.

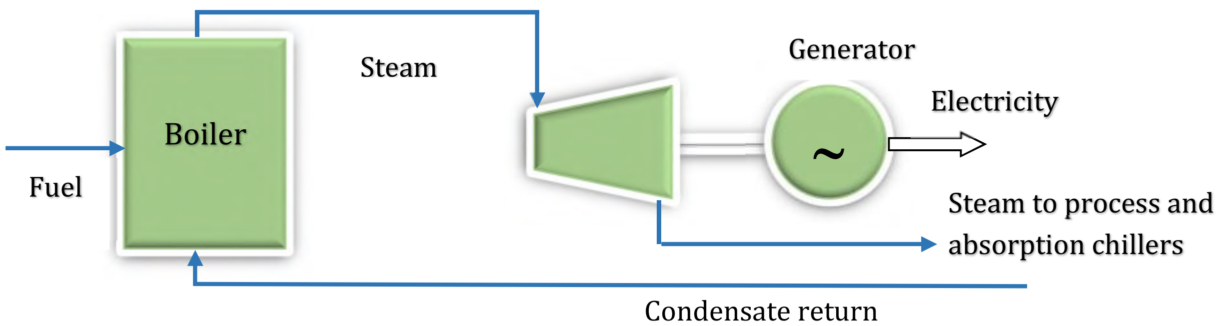

Figure 2.1 Back pressure steam turbine system

The main advantage of such a system is the high overall efficiency because process heating applications are used as a heat sink to eliminate the need for a condenser which otherwise would reject heat to the environment.

One of the main disadvantages is that the steam flow rate and therefore, the system output is governed by the thermal load which is the heat sink. Hence, this system provides little flexibility for matching the electrical output to the actual electrical load. Another disadvantage of the backpressure steam turbine is that it tends to be larger in size (for the same electrical output) as the reduction in enthalpy of steam is lower.

Backpressure steam turbines are generally used for applications that have a heat to power ratio of 4.0 to 14.3 kW_t/kW_e and an electrical output of more than a few MW.

2.1.2 Condensing Steam Turbine

The operation of a condensing turbine is similar to a back pressure turbine except that steam is exhausted from the turbine at a pressure lower than the atmospheric pressure to maximize the electrical generation output.

Since the steam available at the exit of the turbine would not be suitable for industrial applications, steam required for heating applications (including absorption chillers) is taken from an intermediate stage of the turbine. The low pressure steam at the exit of the turbine is exhausted to a condenser which acts as the main heat sink.

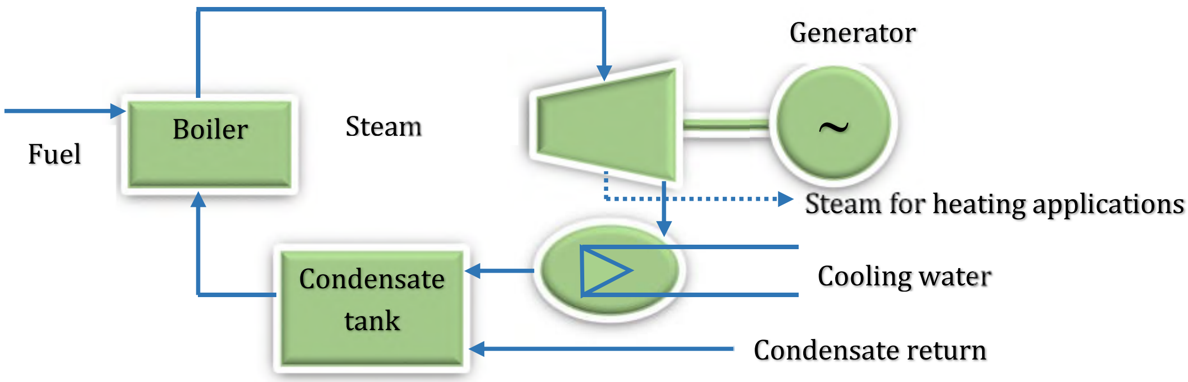

Figure 2.2 Condensing steam turbine system

Condensing steam turbines are generally used for applications where the heat to power ratio in the range of 2.0 to 10.0 kW_t/kW_e and the electrical output is more than a few MW.

2.2 Combustion Turbine (gas turbine)

In the gas turbine power generation cycle, air enters the compressor at atmospheric pressure where it is compressed. It then enters a constant-pressure combustion chamber where fuel is injected. The exhaust gasses then leave the combustor at a high temperature of around 1200°C and enter a gas turbine coupled to a generator. The hot gases after expansion leave the turbine at a temperature of about 450-600°C. The arrangement of a typical system is shown in Figure 2.3. The power generation efficiency of gas turbine systems is relatively low due to the need to discharge of high temperature gases with considerable amount of heat energy at the exit of the turbine.

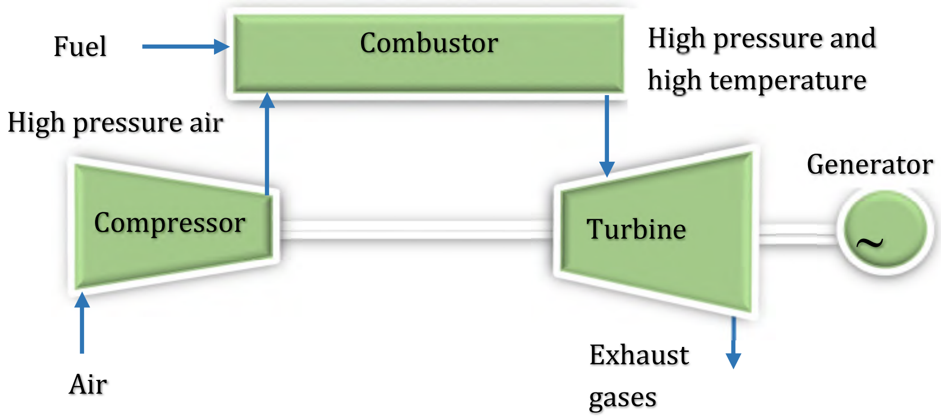

Figure 2.3 Open cycle gas turbine cycle

The overall efficiency of the above system can be improved considerably if the waste heat available at the exit of the turbine is used for heating applications. This is usually achieved by directing the hot gases after the expansion process to a waste heat boiler. The steam produced by the waste heat boiler can be used directly for heating applications or in high capacity systems, the high pressure steam can be expanded through a steam turbine coupled to a generator prior to using the low pressure steam for heating applications. A typical arrangement tri-generation system using a combustion gas turbine is shown in Figure 2.4.

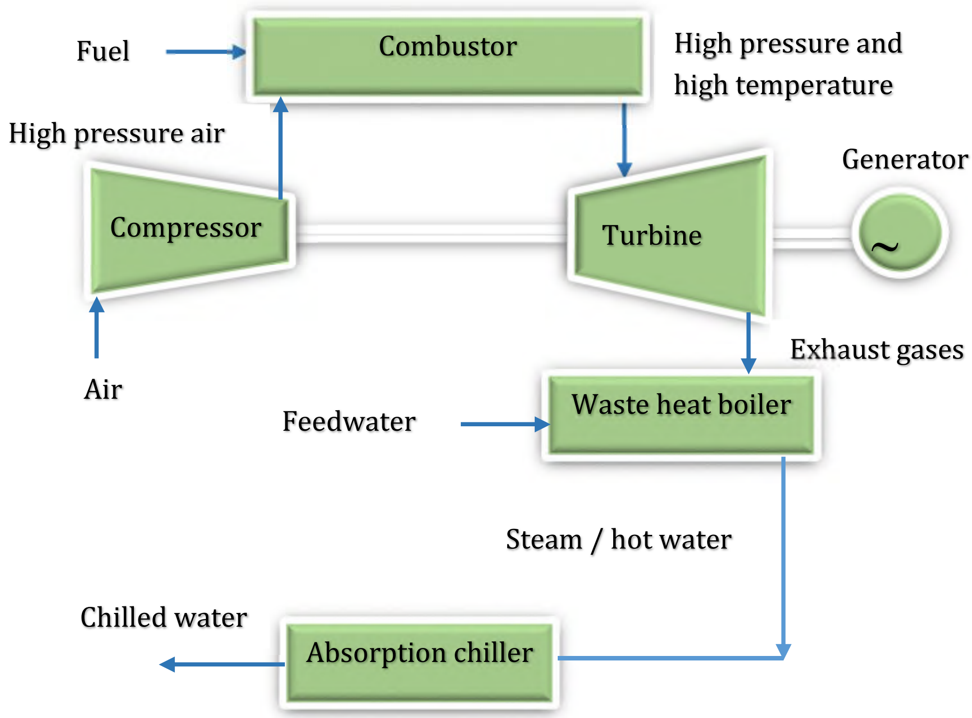

Figure 2.4 Tri-generation system with combustion turbine

Combustion turbine systems are generally used for applications where the heat to power ratio is in the range of 1.3 to 2.0 kW_t/kW_e and the electrical output is more than a few MW.

2.3 Internal Combustion Reciprocating Engines

The internal combustion engine works on the principle of the Otto cycle or the diesel cycle. The Otto cycle is made up of four stages; the intake stroke where a mixture of air and fuel is taken in to a cylinder, the compression stroke where the mixture is compressed by a piston, the power stroke where the fuel air mixture is ignited and expanded moving a piston which does mechanical work followed by the final stage where the exhaust is released to the atmosphere.

The internal combustion engines operating on the Otto cycle can be fueled by a wide variety of fuels. They include liquids such as gasoline and heavy oil as well as gases such as propane, biogas or natural gas.

In an internal combustion engine operating on the diesel cycle, diesel based fuels are used instead of petroleum based fuels. The main difference in the cycle is that the fuel air mixture is ignited by the heat generated by the combustion.

Internal combustion engines can be coupled to generators for power generation. However, the overall operating efficiency is relatively low as a significant portion of the heat input in the fuel is wasted in the form of hot exhaust gases and jacket cooling.

Therefore, the overall operating efficiency of internal combustion engine driven power generation system can be improved significantly by operating as a combined heat and power generation system.

Figure 2.5 shows the arrangement of a typical tri-generation system using an internal combustion engine where hot water from jacket cooling is used for operating an absorption chiller and the exhaust gases are used to generate steam for process heating applications.

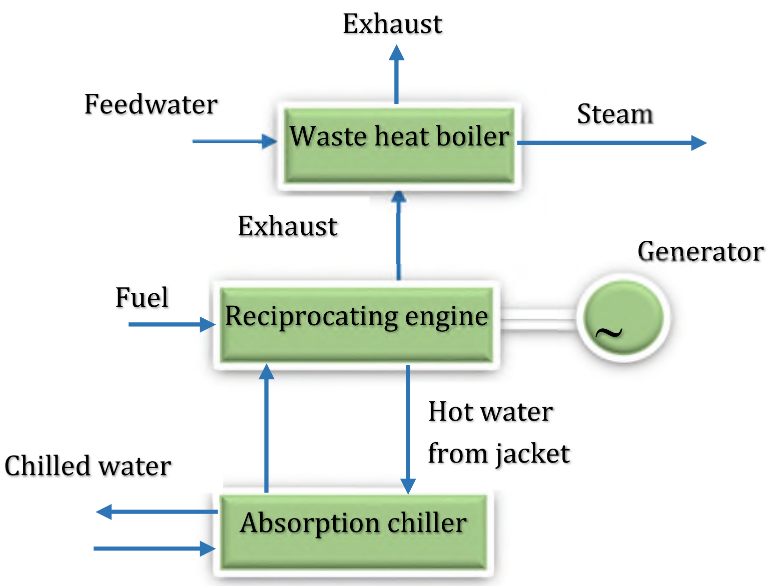

Figure 2.5 Arrangement of an internal combustion engine tri-generation system

The general sizes of internal combustion engines which can be used for such applications range from about 50 kW to around 5 MW. The heat to power ratio for such systems range from 1.1 to 2.5 kW_t/kW_e.

2.4 Micro turbines

Micro turbines are essentially a smaller version of combustion turbine generators. They are available in output sizes ranging from 25 to 250 kW. Micro turbines are also designed to operate on a variety of gaseous fuels such as natural gas, biogas and propane. When used purely for electricity generation, their operating efficiency tends to be relatively low.

Due to the high heat content of the exhaust gases, the overall efficiency of power generation using micro turbines can be improved by using the waste heat from the exhaust for heating and cooling applications.

A typical arrangement of tri-generation system using micro turbines is shown in Figure 2.6.

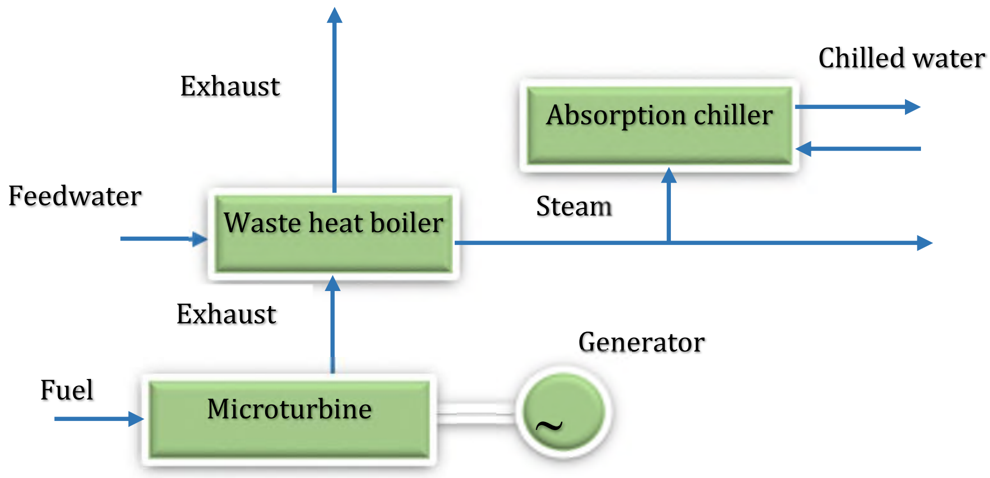

Figure 2.6 Arrangement of a micro turbine tri-generation system

Single micro turbines can produce electrical power output up to about 250 kW. The typical heat to power ratio for such systems range from 1.4 to 2.5 kWt/kWe as summarised in table 2.2 below.

2.5 Summary of Systems

A summary of the key features of the systems described in this chapter are tabulated in Table 2.1.

Technology	Steam Turbine	Combustion Turbine	Internal combustion Engine	Micro turbine
Size (MW)	0.5 - 150	1 - 200	0.05 - 10	0.025 - 0.25
Electric Efficiency (%)	25 - 40	25 - 40 (simple) 40 - 60 (combined cycle)	30 - 50	20 - 30
Overall system efficiency (%)	60 - 80	75 - 80	75 - 85	65 - 80
Typical uses of heat recovery	Hot water, LP steam, cooling	Hot water, LP-HP steam, cooling	Hot water, LP steam, cooling	Hot water, LP steam, cooling
Fuels	Solid, liquid and gaseous fuels	Natural gas, biogas, propane, distillate oil	Diesel and fuel oil	Natural gas, biogas, propane
Relative operational & maintenance expertise required	High	High	Low	Medium
Relative capital cost for system	High	High	Medium	Low
Heat to power ratio	2.0 – 10.0	1.3 – 2.0	1.1 - 2.5	1.4 - 2.5

Table 2.1 Summary of the common technologies available for tri-generation

3.0 METHODOLOGY

3.1 Selection of Hotels

The feasibility study commenced by first identifying suitable hotels for inclusion in the study. Since tri-generation systems would need a reasonable demand for electricity and heat, only hotels with at least a 100 guest rooms were considered for the study.

A list of registered hotels in Sri Lanka with over 100 guest rooms was compiled and the largest 30 hotels were shortlisted for participation in this study.

3.2 Information gathering

Subsequently a questionnaire (survey form) was sent to each of the selected hotels requesting for information. The information requested in the survey form included the following:

- Location
- Number of guest rooms
- Total hotel gross floor area
- Average monthly occupancy during last 24 months
- Monthly electrical energy consumption for the last 24 months
- Monthly solid and liquid fuel usage for the last 24 months
- Past electricity and fuel cost
- Cooling capacity and operating cooling load
- Boiler and calorifier capacity
- Fuel storage capacity
- Gen-set capacity and age
- Data on hot water and steam usage
- Average operating hours of the laundry
- Other relevant information

3.3 Data Collection and Analysis

The key parameters required for establishing the feasibility of implementing a tri-generation system are the electricity and heat requirements of the hotel. Therefore, from the survey information received, the average daily electrical consumption of each hotel was established. Similarly, the average daily thermal load (steam generation) was also estimated for each hotel.

3.3.1 Heat to Power Ratio

One of the most important parameters to be considered when evaluating the feasibility of tri-generation systems is the “Heat to Power ratio”. The heat to power ratio is the ratio of the heat energy load (steam and or hot water) to the power (electrical) load. In general, higher the heat to power ratio, better will be the operating efficiency of the heat and power generation system.

The optimum operating heat to power ratio for the different systems varies and are summarized in Table 2.1. Therefore, once all the data was collected, the present heat to power ratio (equation 2.1) for the different hotels was computed with the objective of identifying the achievable system efficiency as well as the most suitable type of heat and power generation system. Since most of the thermal energy requirement of hotels is for laundry operations, the heat to power ratio was computed only during laundry operating hours.

$$\text{Present heat to power ratio} = \frac{\text{total thermal load (kW)}}{\text{electrical power demand (kW)}} \qquad (2.1)$$

3.3.2 Maximising Power Generation and Heat Output

When selecting suitable heat and power generation systems, the objective would be to maximize the heat to power ratio to optimize the operating efficiency. Therefore, it would be best to design the system to maximize the heat output based on the needs of the hotels rather than their electricity requirements. Under such a design condition, the amount of electricity generated may not be sufficient to supply for all the needs of each hotel and a portion of the electricity may still have to be obtained from the grid.

However, since a significant portion of electricity used in hotels is used for providing air conditioning, the total electricity requirement can be reduced by using part of the heat produced by a combined heat and power system (other than heat used for producing steam), to operate absorption chillers which can produce cooling (chilled water) for hotels. This would improve and optimize the heat to power ratio.

Hence, the cooling requirements of the hotels were also analysed to study the possibility of providing all or some of the cooling requirements using absorption chillers operating on waste heat from the combined heat and power system. Thereafter, the highest possible heat to power ratio that could be achieved was computed using equation 2.2.

$$\text{Potential heat to power ratio} = \frac{\text{total heat output for steam and hot water for absorption chiller (kW)}}{\text{total present electrical power demand} - \text{possible reduction in power demand of electric chillers (kW)}} \qquad (2.2)$$

3.3.3 Financial Analysis

Since a tri-generation system will act as a means to offset the electricity taken from the grid, the main benefit would be reduction in electricity charges paid to the utility company. However, fuel would be required to generate electrical power. Although heat produced by the electricity generation system would be used to meet all or part of the heat load of hotels, the overall fuel usage would increase. Therefore, the overall cost savings can be computed using equation 2.3.

$$\text{Annual cost savings} = [(kWh_{pre} - kWh_{post}) \times E_{tariff}] - [(Fuel_{post} - Fuel_{pre}) \times Fuel_{cost}] - M_{cost} \qquad (2.3)$$

kWh_{pre} = present annual electricity consumption from the grid
kWh_{post} = projected annual electricity consumption from the grid with tri-generation system
E_{tariff} = electricity tariff
$Fuel_{pre}$ = present annual fuel consumption
$Fuel_{post}$ = projected annual fuel consumption with tri-generation system
$Fuel_{cost}$ = cost of fuel per unit of fuel used
M_{cost} = annual maintenance cost of operating the system
(demand savings are not computed as power generation will be possible only for part of the day when the respective hotel laundry is in operation)

In the economic analysis, the capital cost of the proposed system together with the estimated savings achievable were considered.

4.0 SUMMARY OF DATA COLLECTED

Data collected from hotels is summarised in Tables 4.1 to 4.3.

4.1 Energy Usage

Hotel	Average daily electricity consumption (kWh)	Average daily fuel usage (litres)	Type of fuel
1	20,553	980	Furnace oil
2	25,504	2187	Furnace oil
3	8,079	384	Furnace oil
4	9,604	517	Diesel
5	24,700	1770	Furnace oil
6	16,560	871	Furnace oil
7	16,824	799	Furnace oil
8	10,240	447	Diesel
9	37,397	1781	Furnace oil

Table 4.1 Daily energy usage data

4.2 Heat and Cooling Requirements

Hotel	Average daily steam usage (kg/day)	Steam pressure (bar)	Laundry operating hours per day	Average daytime cooling load (RT)
1	13,141	7	12	450
2	29,315	6.2	12	550
3	5,154	10	14	204
4	6,648	10.4	11	240
5	23,730	7.5	15	540
6	11,672	7.5	16	349
7	10,713	7	12	320
8	5,747	7.5	10	230
9	23,871	7.3	15	1000

Table 4.2 Average heat and cooling requirements

4.3 Other Data

Hotel	Occupancy range (%)	Capacity of existing electricity gensets (kVA)	Age of gensets (years)	Fuel storage capacity (litres)
1	48 - 87	3,025	8 to 18	32,100
2	21 - 50	3,250	11 to 30	35,000
3	34 - 100	1,462	-	15,537
4	46 to 96	1,620	2 to 11	23,500
5	48 to 55	3,000	-	20,000
6	71 to 90	1,400	-	26,400
7	44 to 86	1,650	Over 10	23,575
8	50 to 70	1,450	19	26,400
9	64 to 88	3,650	-	79,000

Table 4.3 Other data

Energy Cost

Most of the hotels are under the H3 tariff which is as follows:

18.30 to 22.30	LKR 23.50 / kWh
05.30 to 18.30	LKR 13.70 / kWh
22.30 to 05.30	LKR 8.80 / kWh

Average diesel cost is LKR 120 /lit (reduced to LKR 95 / lit in 2015)
Average furnace oil cost is LKR 92.20 /lit (reduced to LKR 82.20 / lit in 2015)

The data collected was analysed to study the feasibility of using tri-generation systems for producing power, heat and cooling for hotels and is presented in the following chapter of this report.

5.0 DATA ANALYSIS

The data received from the participating hotels was analysed to identify their heat and electrical energy demand. Thereafter, the heat to power ratio was computed for the present operation as well as the value achievable with tri-generation, and are presented in this section of the report.

5.1 Heat Generation

Hotel	Average daily steam usage (kg/day)	Steam usage during daytime with laundry operation (kg/hr)	Average heat output in steam during daytime (kW_t)
1	13,141	920	606
2	29,315	2,052	1,351
3	5,154	361	238
4	6,648	465	306
5	23,730	1,661	1,094
6	11,672	817	538
7	10,713	750	494
8	5,747	402	265
9	23,871	1,671	1,100

Table 5.1 Average heat output of steam

Notes:
Based on the normal operating conditions of hotels, the daytime steam consumption was taken to be 70% of the daily total steam usage while the heat output was computed using the enthalpy of feedwater at 95^{o}C and enthalpy of saturated steam at 7 bar.

5.2 Electrical Power Requirements for Present Operation

Hotel	Average daily electricity consumption (kWh/day)	Estimated electricity consumption during daytime (kWh/day)	Present daytime electrical power demand ($kW_{e\text{-}pre}$)
1	20,553	12,332	1028
2	25,504	15,302	1275
3	8,079	4,848	404
4	9,604	5,762	480
5	24,700	14,820	1235
6	16,560	9,936	828
7	16,824	10,094	841
8	10,240	6,144	512
9	37,397	22,438	1870

Table 5.2 Electrical power for present operation

Notes:
Daytime electrical consumption was taken as 60% of the daily total electricity usage while the present daytime power was computed taking the daytime operating hours as 12 hours a day.

5.3 Electrical Power Requirements with Tri-generation

Hotel	Present daytime electrical power demand ($kW_{e\text{-}pre}$)	Daytime cooling load (RT)	Reduction in electrical power by using absorption chillers (kW)	Daytime electrical power demand with tri-gen. ($kW_{e\text{-}tri}$)
1	1028	450	338	690
2	1275	550	413	863
3	404	204	153	251
4	480	240	180	300
5	1235	540	405	830
6	828	349	262	566
7	841	320	240	601
8	512	230	173	340
9	1870	1000	750	1,120

Table 5.3 Electrical power tri-generation

Notes:
The reduction in chiller power consumption was estimated assuming the present chiller system efficiency to be 0.75 kW/RT.

5.4 Heat to Power Ratio

The heat to power ratio computed based on the current operation is presented in Table 5.4.

Hotel	Present average heat demand during daytime (kW_t)	Present daytime electrical power demand ($kW_{e\text{-}pre}$)	Present heat to power ratio (kW_t / $kW_{e\text{-}pre}$)
1	505	1028	0.49
2	1,126	1275	0.88
3	198	404	0.49
4	255	480	0.53
5	911	1235	0.74
6	448	828	0.54
7	411	841	0.49
8	221	512	0.43
9	917	1870	0.49

Table 5.4 Heat to power ratio for present operation

Since the present heat to power ratio is low, the heat to power ratio achievable with tri-generation (using part of the heat to produce cooling) which would help to increase the heat requirement while reducing the power requirement was computed and the data is presented in Table 5.5.

Hotel	Daytime cooling load (RT)	Average heat demand during daytime with tri-gen (kW_t)	Daytime electrical power demand with tri-gen. (kW_{e-tri})	Heat to power ratio with tri-gen (kW_t / kW_{e-tri})
1	450	2263	690	3.28
2	550	3275	863	3.80
3	204	995	251	3.97
4	240	1193	300	3.97
5	540	3022	830	3.64
6	349	1813	566	3.20
7	320	1662	601	2.76
8	230	1120	340	3.30
9	1000	4824	1,120	4.31

Table 5.5 Heat to power ratio with tri-generation

Notes:
The COP (coefficient of performance) of the absorption chiller used for tri-generation was taken as 0.9.

5.5 Data Correlation

Figures 5.1 to 5.3, show the correlation between some of the important parameters and hotel size.

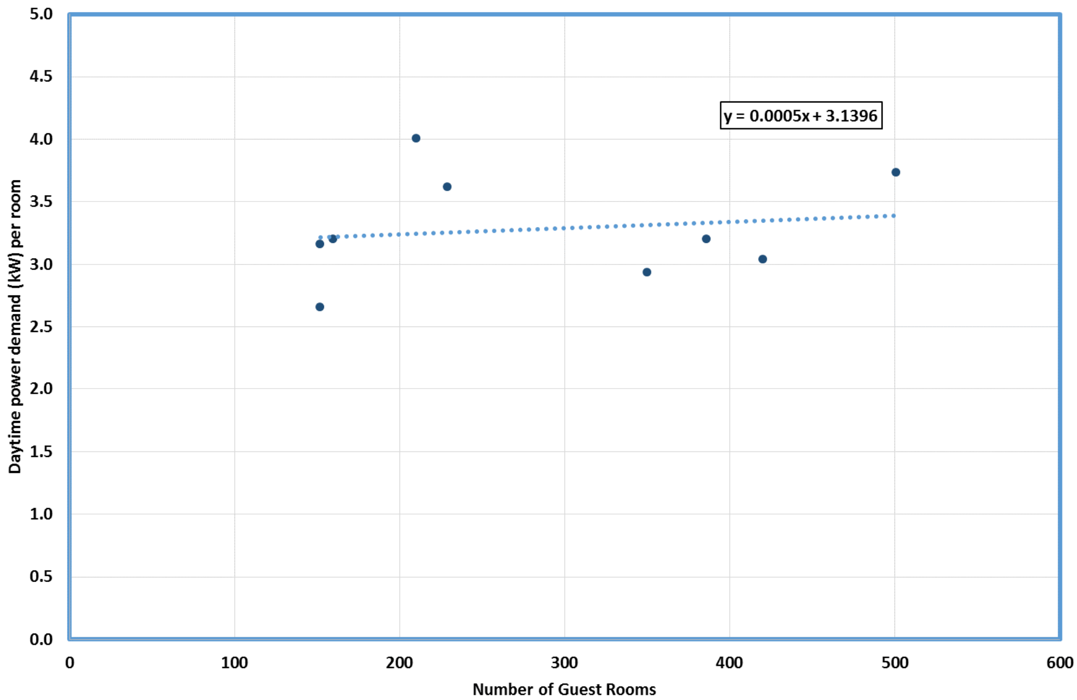

Figure 5.1 Electrical power demand (kW) vs number of rooms

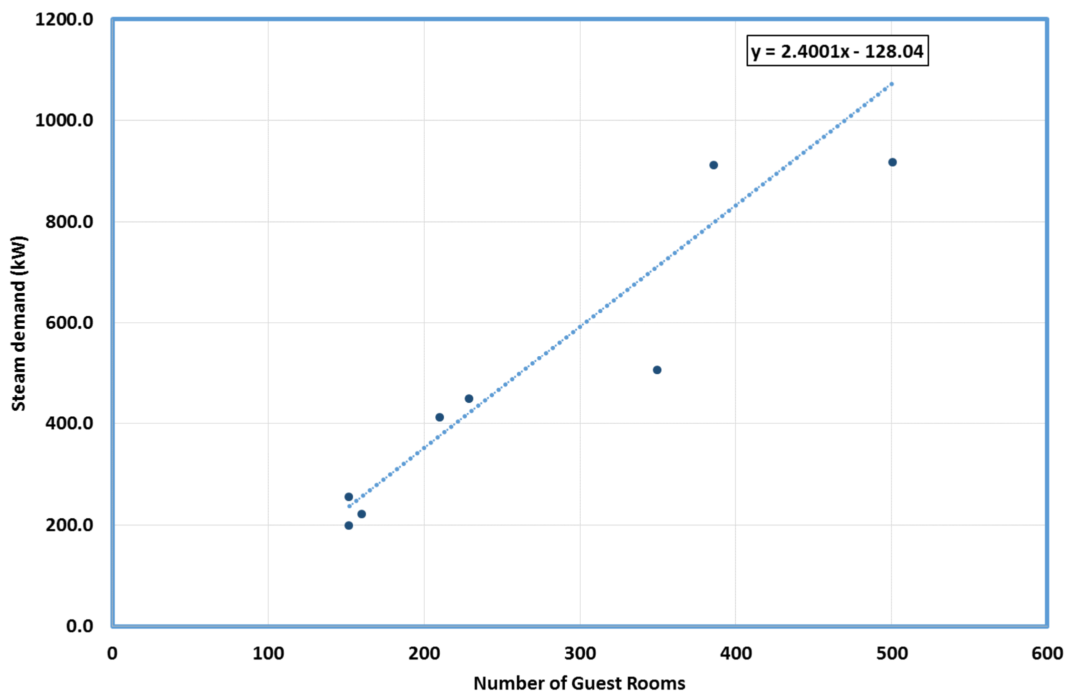

Figure 5.2 Daytime steam load (kW) vs number of rooms

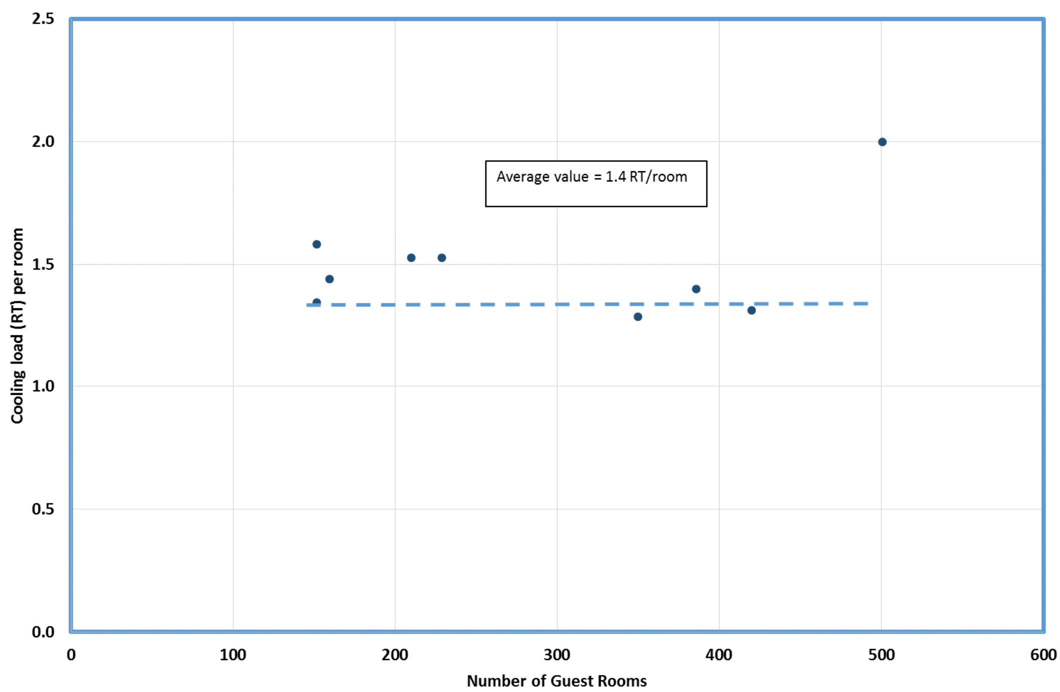

Figure 5.3 Cooling load (RT) vs number of rooms

From the above data analysis (Tables 5.1 to 5.5 and Figures 5.1 to 5.3), the main findings can be summarized as follows:

1. The relationship between the daytime hotel power demand in kW and the number of guest rooms can be represented using the correlation,

kW/room = 0.0005 x N + 3.1396, where N = no. of guest rooms (5.1)

2. The relationship between the daytime thermal demand in kW and the number of guest rooms can be represented using the correlation,

   kW/room = 2.40001 x N – 128.04, where N = no. of guest rooms (5.2)

3. The relationship between the daytime cooling load in RT and the number of guest rooms can be represented using the correlation,

   Cooling load (RT) = 1.4 x N, where N = no. of guest rooms (5.3)

4. The heat to power ratio based on present operation ranges from about 0.5 to 0.9

5. The heat to power ratio can be improved to 2.8 to 4.3 by including tri-generation.

5.6 Estimated Electrical Power and Thermal Demand for Hotels

Using the findings in section 5.5 (equations 5.1 to 5.3), the electrical power and thermal demand characteristics projected for different hotel sizes (based on the number of guest rooms) is shown in Table 5.6.

Hotel size	Present daytime electrical power demand ($kW_{e\text{-}pre}$)	Present average heat demand during daytime (kW_t)	Present heat to power ratio (kW_t / $kW_{e\text{-}pre}$)
150	482	279	0.58
200	648	423	0.65
250	816	567	0.69
300	987	711	0.72
350	1160	855	0.74
400	1336	999	0.75
450	1514	1143	0.75
500	1695	1287	0.76

Table 5.6 Estimated electrical and thermal demand based on present operations

Similarly, the achievable electrical power and thermal demand characteristics with tri-generation for different hotel sizes (based on the number of guest rooms) was projected and is shown in Table 5.7.

Hotel size	Daytime cooling load (RT)	Daytime electrical power demand with tri-gen. (kW_{e-tri})	Average heat demand during daytime with tri-gen (kW_t)	Heat to power ratio with tri-gen (kW_t / kW_{e-tri})
150	210	325	1100	3.4
200	280	438	1517	3.5
250	350	554	1935	3.5
300	420	672	2352	3.5
350	490	793	2770	3.5
400	560	916	3187	3.5
450	630	1042	3605	3.5
500	700	1170	4023	3.4

Table 5.7 Estimated electrical and thermal demand possible with tri-generation

6.0 RECOMMENDATIONS

Although many technologies are available for tri-generation (as described in Chapter 3), the larger scale steam turbine and combustion gas turbine systems are not suitable for the hotel industry since their power and heat requirements are relatively low (Tables 5.6 and 5.7).

Therefore, only medium size systems which use internal combustion engine generators and smaller scale micro turbine systems would suit the relatively low heat and power demand of hotels.

Out of the above two technologies, internal combustion engine based generators are the most suitable due to the following reasons:

- Power generation capacity of typical generator units of 0.3 to 2 MW best suit the needs of the hotels
- Heat output from internal combustion engines can be extracted from the exhaust gases for steam generation as well as lower grade heat can be recovered from jacket cooling for hot water generation (for operating absorption chillers to produce chilled water)
- They can use commonly available fuels such as fuel oil and diesel as compared to micro turbines which require gaseous fuels
- The availability of such generators in most hotels for back-up power generation
- Familiarity with the operation and maintenance of engines as compared to specialized skills required for micro turbines

Due to the above reasons, it is clear that only internal combustion engine generators would be suitable for tri-generation in hotels. Therefore, only this type of generator was used for further analysis in this study.

6.1 Current Situation

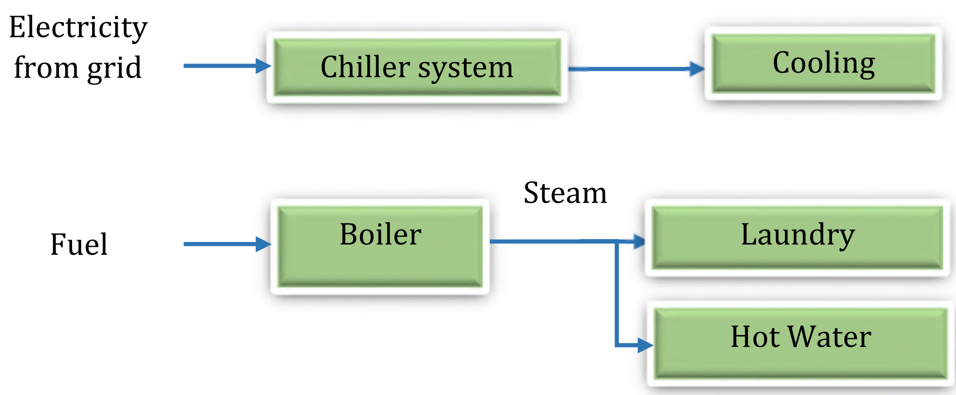

Figure 6.1 Present hotel operations

Figure 6.1 shows the current operation in hotels where electricity is purchased from the grid while boilers operating on fuel are used to generate steam to meet their laundry and hot water requirements.

6.2 Tri-generation

Tri-generation will involve generating heat to match the hotel's requirements for steam while extracting waste heat (jacket cooling) from the power generation system to operate an absorption chiller to produce chilled water. Such a system would help to maximize the heat output from the generator and improve the overall heat to power ratio.

The proposed arrangement of the tri-generation system is shown in Figure 6.2.

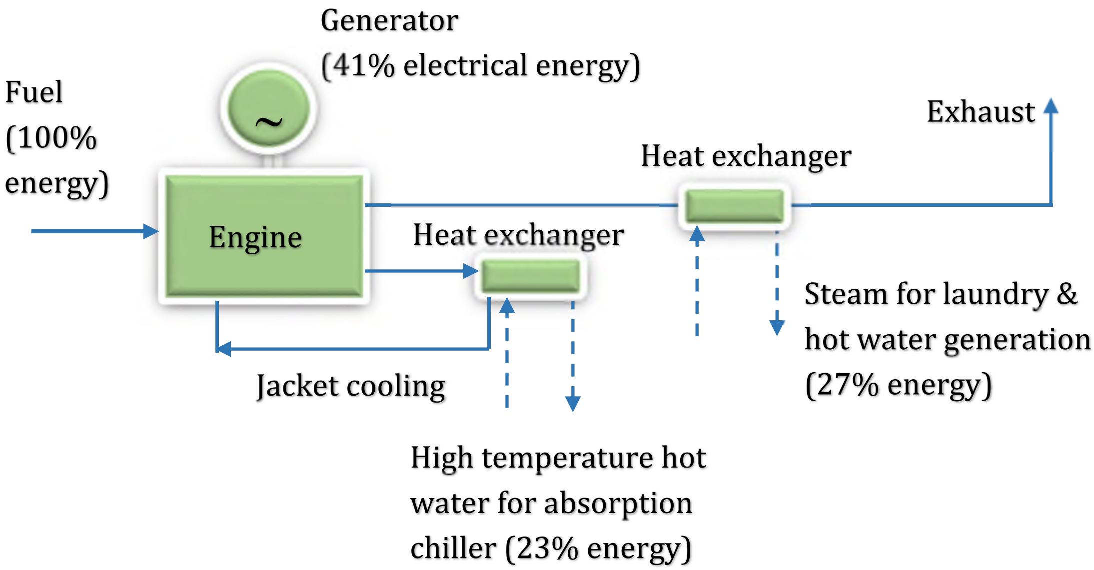

Figure 6.2 Proposed arrangement for tri-generation

When sizing combined heat and power systems, the two most commonly used strategies are heat matching and power matching. "Heat matching" involves sizing the system so that the heat output matches the actual demand while the electrical power output generated by the system is used to satisfy the load partially with the remaining power supply obtained from the grid.

However, if the heat to power ratio is high, sizing the system based on the heat demand would result in a system that would produce more electrical power than required. In such cases, "power matching" is used where the system is sized based on the power demand while the heat generated is used to partially meet the thermal demand (while the rest of the thermal load is provided by other means).

Therefore, to be able to identify the most suitable design, the heat and electrical and power demand for the various sizes of hotels are compared in Tables 6.1 and 6.2.

Hotel size	Steam heat output (kW)	Electrical power output (kW)	Cooling Produced (kW)	Electrical power demand (kW)	Electrical power output – demand (kW)
Note	A	B	C	D	E
150	279	424	214	437	-13
200	423	642	324	579	64
250	567	861	435	723	138
300	711	1080	545	871	209
350	855	1298	656	1020	278
400	999	1517	766	1172	345
450	1143	1736	876	1327	409
500	1287	1954	987	1484	470

Table 6.1 Heat matching for tri-generation

Notes:
Note A: Total heat demand from equation (5.1)
Note B: Based on generator output (Figure 6.2)
Note C: Based on generator output (Figure 6.2) and taking absorption chiller COP as 0.9
Note D: From equation (5.1)
Note E: Column B – Column D

Hotel size	Cooling produced (kW)	Reduction in electrical load (kW)	Net electrical load (kW)	Heat output (kW)	Heat demand (kW)	Heat output – demand (kW)
Note	A	B	C	D	E	F
150	214	46	437	287	279	8
200	324	69	579	381	423	-42
250	435	93	723	476	567	-91
300	545	116	871	573	711	-138
350	656	140	1020	672	855	-183
400	766	163	1172	772	999	-227
450	876	187	1327	874	1143	-269
500	987	210	1484	978	1287	-310

Table 6.2 Power matching for tri-generation

Notes:
Note A: Column C of Table 6.1 (to avoid iterative calculation to establish suitable cooling output)
Note B: Taking average chiller efficiency of 0.75 kW/RT
Note C: Column D of Table 6.1 minus Column B of Table 6.2
Note D: Based on generator output (Figure 6.2)
Note E: From equation (5.1)
Note F: Column D – Column E

Tables 6.1 indicate that heat matching is not suitable other than for small Hotels of about 150 rooms as the electrical power output generated would be more than the actual demand.

On the other hand, Table 6.2 indicates that power matching would be suitable for all hotel sizes as the heat generated would be less than the demand (the remaining portion of heat can be produced by conventional means).

The energy cost savings achievable by tri-generation for the various hotels based on power matching is presented in Table 6.3.

Hotel size	Fuel cost for generator (LKR/year)	Electrical savings (LKR/year)	Fuel savings for steam generation (LKR/year)	Overall savings (LKR/year)
Note	A	B	C	D
150	44,504,423	28,934,293	11,728,026	(3,842,104)
200	58,998,945	38,879,088	15,547,695	(4,572,163)
250	73,748,319	48,973,897	19,434,523	(5,339,899)
300	88,752,545	59,218,721	23,388,511	(6,145,313)
350	104,011,624	69,613,561	27,409,659	(6,988,404)
400	119,525,554	80,158,415	31,497,967	(7,869,172)
450	135,294,337	90,853,284	35,653,435	(8,787,618)
500	151,317,972	101,698,169	39,876,062	(9,743,741)

Table 6.3 Cost savings calculation for tri-generation (power matching)

Notes:
Note A: cost of fuel to operate generator on diesel for 12 hours a day (@ LKR 95/lit)
Note B: cost savings due to electricity generated based on grid tariff of LKR 13.70 / kWh
Note C: saving in fuel used currently for steam boiler operating on furnace oil (@LKR 82.2 / lit)
Note D: (B + C) - A

It is clear from Table 6.3 that there will be no cost savings achievable by using tri-generation based on the present cost of fuel and electricity.

7.0 FINANCIAL ANALYSIS

The estimated cost savings achievable for the various alternative systems were computed in Chapter 6 of the report. Unfortunately, the analysis so far indicate that tri-generation is not economically feasible as the cost of operating such a system is higher than the current cost of steam generation and purchase of electricity from the grid.

The two main reasons for the unviability of tri-generation are:

1. Currently, steam is generated in boilers using furnace oil which is about 15% cheaper than diesel or heavy fuel oil that is required to operate electrical power generators
2. Grid electricity tariff is approximately 30% of the cost of electricity generation using electric power generators based on the present fuel cost

However, tri-generation system may become financially viable in the future if the cost of electricity rises relative to the cost of fuel. Therefore, further analysis was conducted to identify the conditions under which such a system can become financially viable.

Although it would be possible to install new generator units which can operate on heavy fuel oil which is about 13% cheaper than diesel, this is not recommended for hotels due to the high noise levels (more than 120 dBA) and vibration levels associated with such generators. Such generators are generally available only for larger size units with capacity over 1000 kVA. In addition, the simple payback period for the additional cost of a new generator (operating on heavy fuel oil) based on fuel cost savings is about 5 years, making this option not viable.

It is clear that to improve the possibility of achieving financial viability, the cost of implementing a new system has to be minimized. This can be achieved by utilizing the existing standby generator sets installed in hotels.

7.1 Cost Estimation

The estimated cost associated with installing a tri-generation system is summarized in Table 7.1. To simplify the computation, it is assumed that there will be no additional manpower cost for operating the system and that the capacity of the currently installed generator units and fuel storage are sufficient.

7.1.1 Tri-generation Systems

Hotel size	Cost of waste heat recovery boiler (LKR)	Cost of hot water heat recovery system (LKR)	Cost of absorption chiller (LKR)	Taxes (LKR)	Installation cost (LKR)	Total cost (LKR)
150	6,637,500	200,000	3,936,594	2,154,819	8,205,000	21,133,912
200	7,241,386	240,000	5,988,058	2,693,889	8,977,664	25,140,997
250	9,375,000	270,000	8,021,041	3,533,208	11,574,000	32,773,249
300	10,819,172	270,000	10,072,505	4,232,335	13,307,006	38,701,018
350	10,887,500	300,000	12,105,488	4,658,598	13,425,000	41,376,585
400	11,401,167	300,000	14,138,470	5,167,927	14,041,400	45,048,964
450	13,150,000	350,000	16,189,935	5,937,987	16,200,000	51,827,922
500	14,687,954	350,000	18,222,917	6,652,174	18,045,545	57,958,591

Table 7.1 Estimated cost for tri-generation systems

7.1.2 Maintenance Cost

The approximate annual maintenance cost for the generator units are summarized below.

Generator size (kVA)	Annual Maintenance cost (USD)
550	3500
750	3700
950	3700
1150	4900
1350	4900
1550	4900
1750	5500
2000	5500

Table 7.2 Estimated annual maintenance cost for generators

Note: Annual cost for generator maintenance is based on 4000 running hours and includes cost for spare parts + lub oil + three of routine inspection/services within 30 km radius from Colombo

7.2 Financial Evaluation

Since tri-generation is not feasible under current conditions, financial evaluation was conducted for the following scenario:

- 15% reduction in fuel cost
- 20% reduction in fuel cost
- 15% increase in electricity tariff
- 20% increase in electricity tariff
- 5% reduction in fuel cost and 10% increase in electricity tariff
- 10% reduction in fuel cost and 10% increase in electricity tariff

The actual cashflows generated are shown in the Appendix.

The simple payback period for the various scenario are shown in Figures 7.1 to 7.6 for hotels with number of guest rooms ranging from 250 to 500 (charts for hotels with 150 and 200 guest rooms are not included as the cashflow analysis in the Appendix indicates that the simple payback period is much more than 10 years).

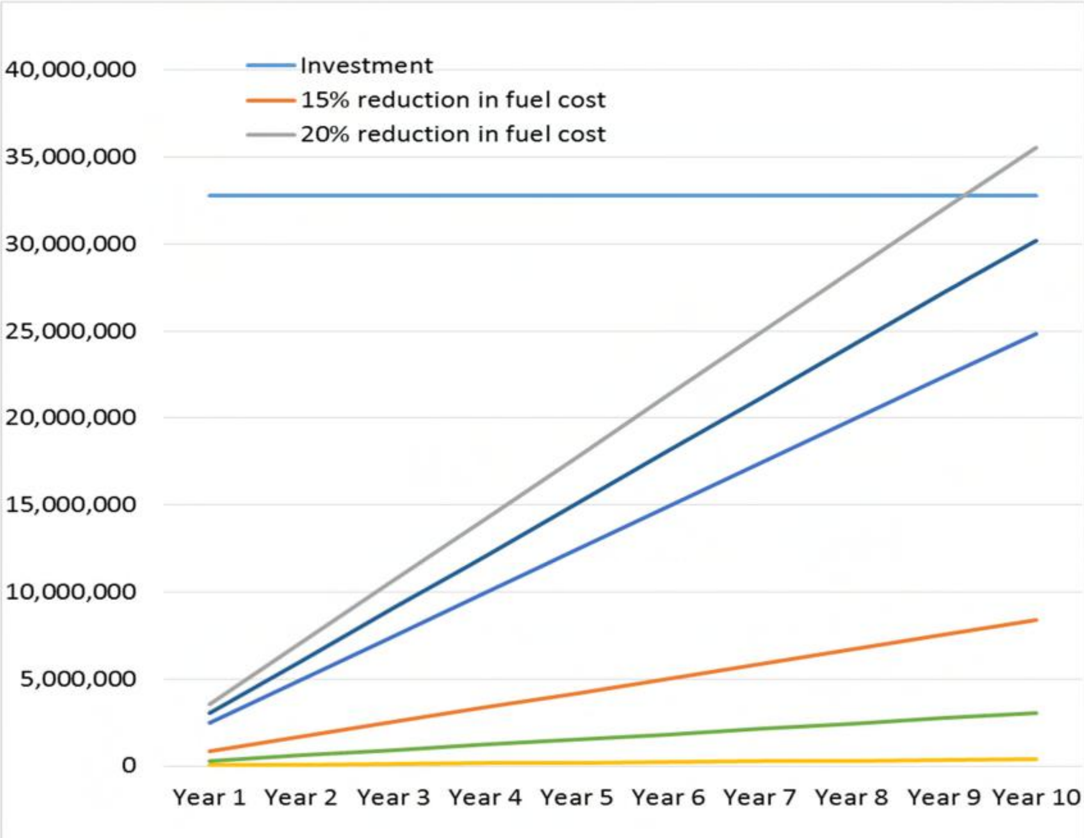

Figure 7.1 Hotels with 250 Guest Rooms

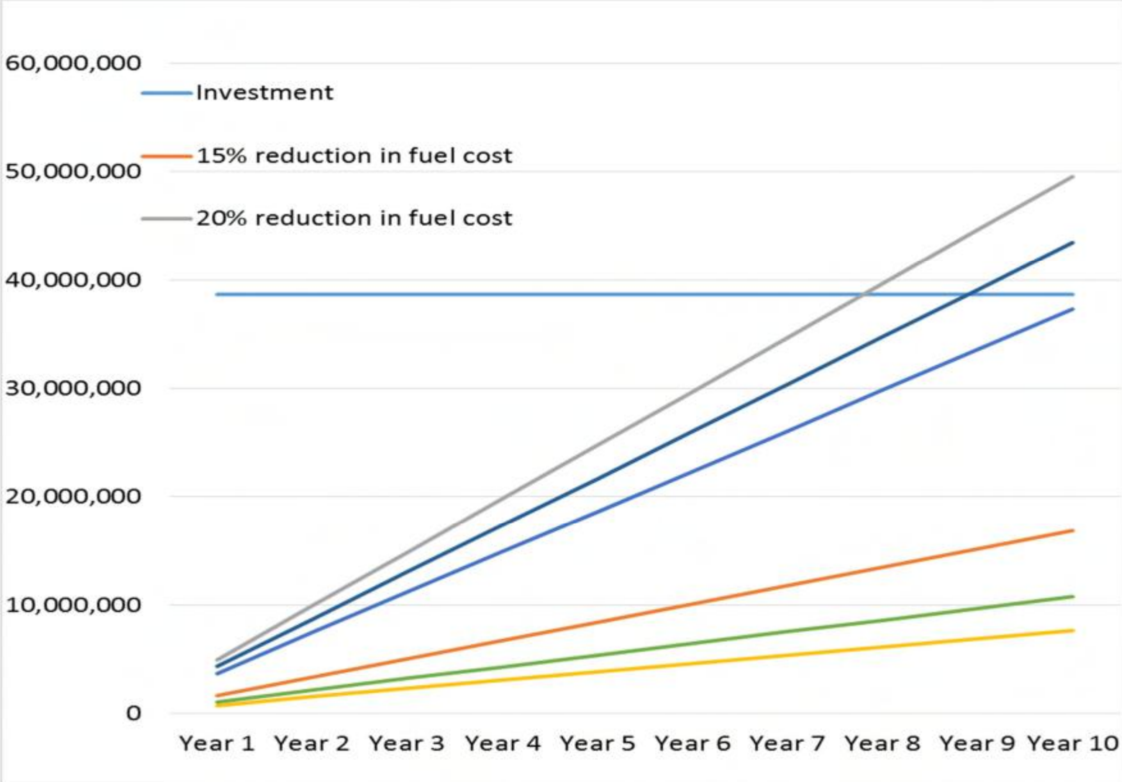

Figure 7.2 Hotels with 300 Guest Rooms

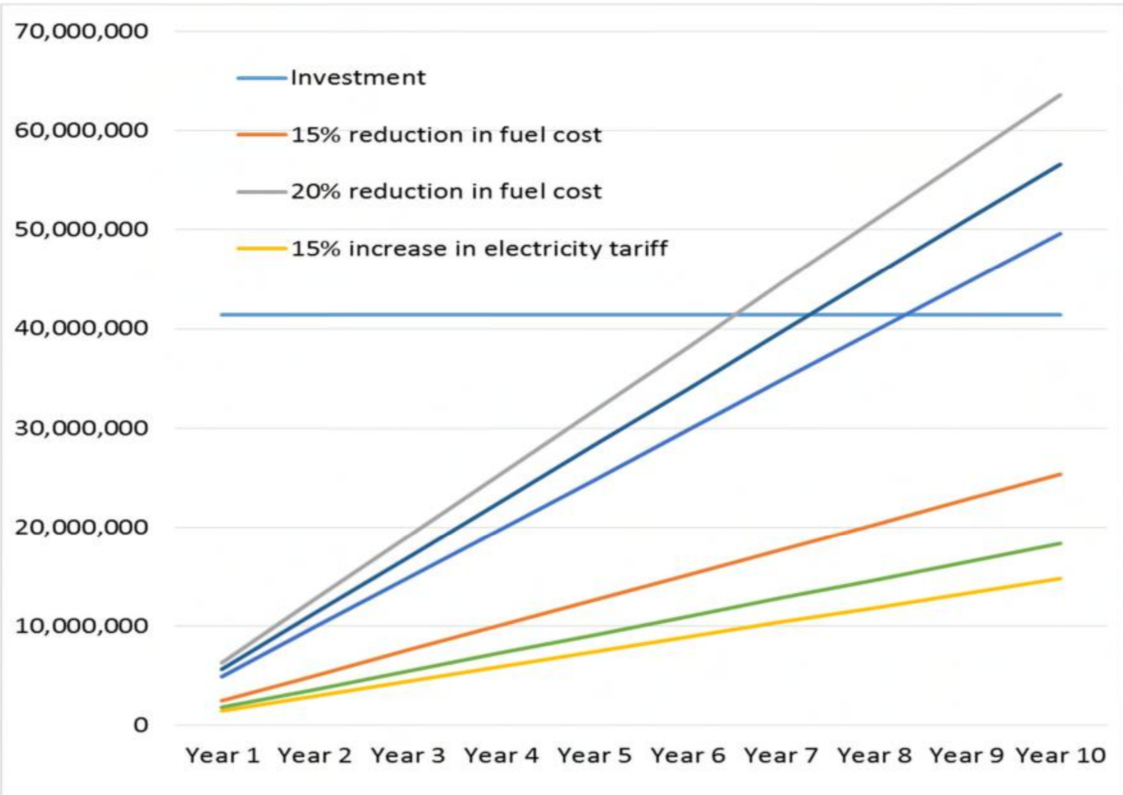

Figure 7.3 Hotels with 350 Guest Rooms

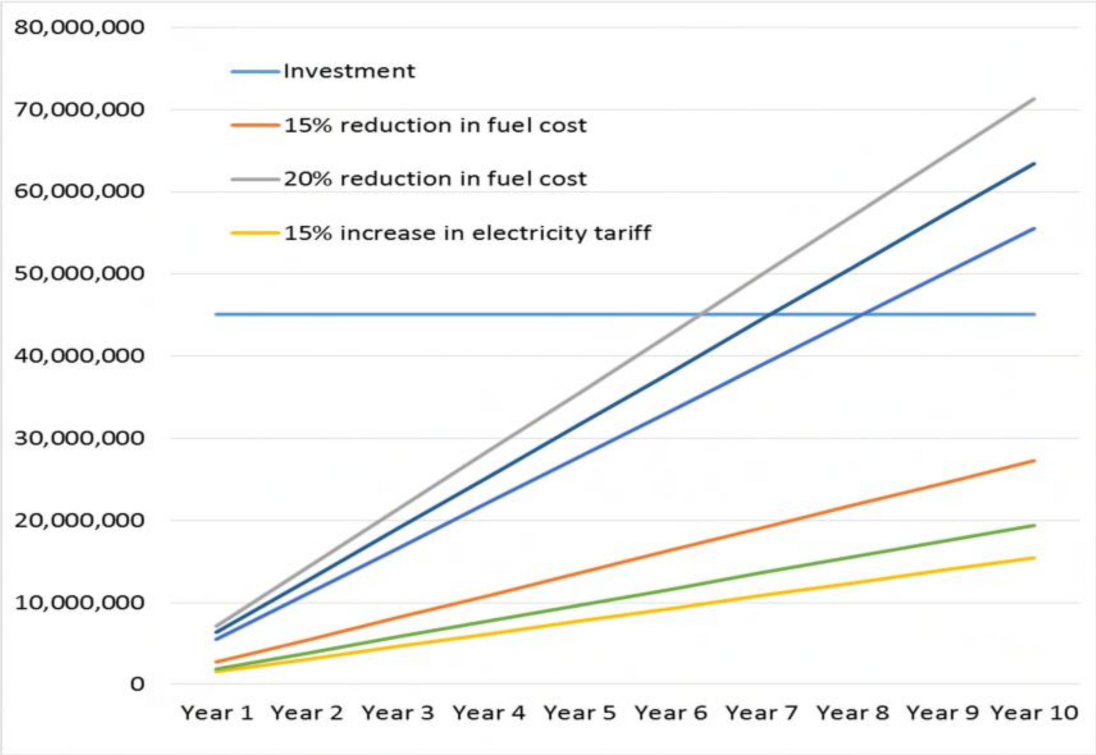

Figure 7.4 Hotels with 400 Guest Rooms

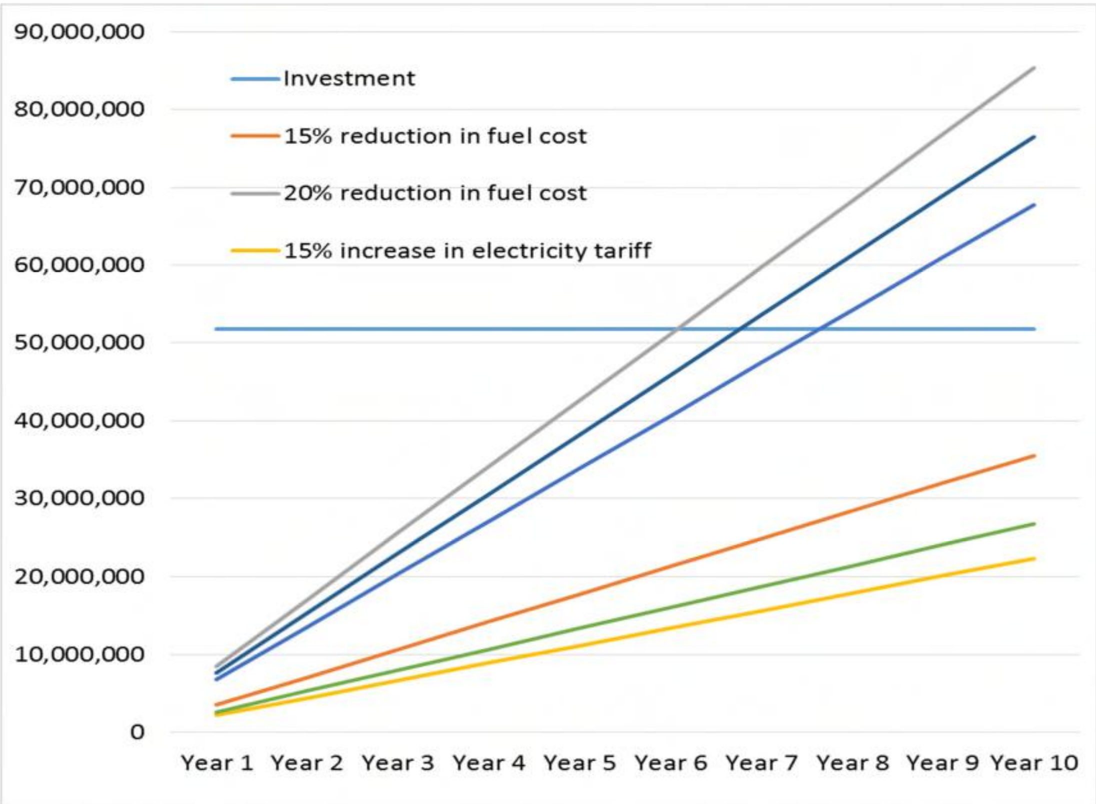

Figure 7.5 Hotels with 450 Guest Rooms

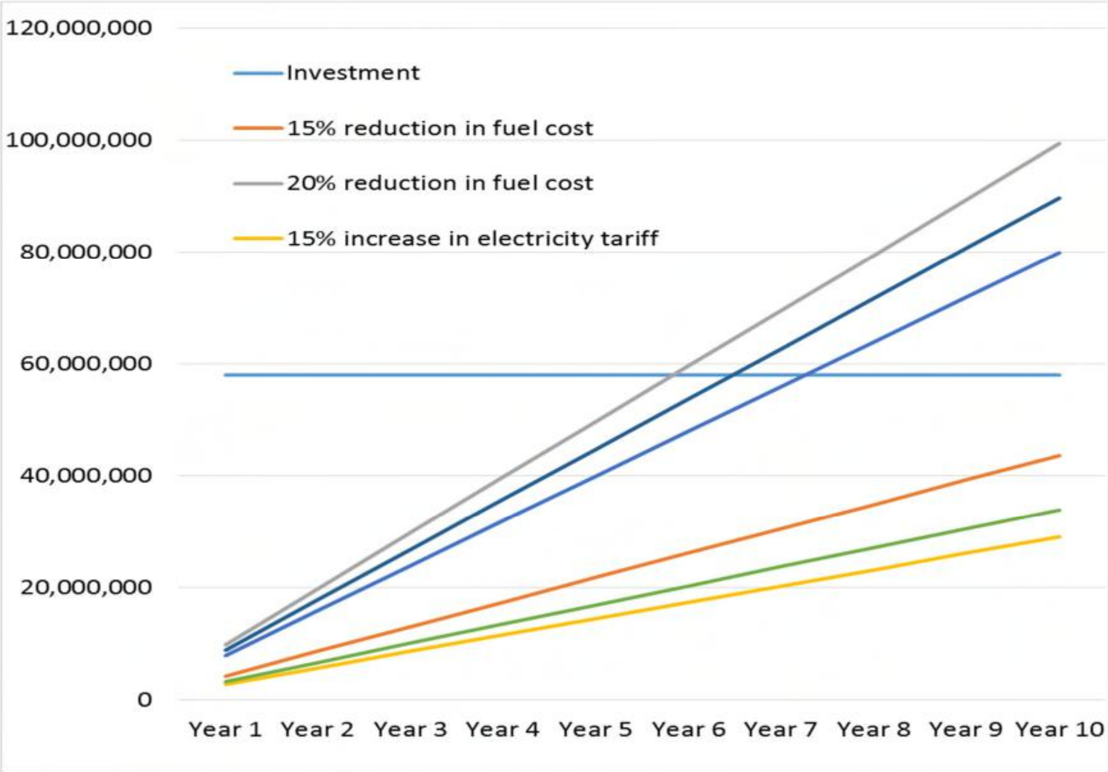

Figure 7.6 Hotels with 500 Guest Rooms

Data from Figures 7.1 to 7.6 are summarized in Table 7.3.

Hotel size	Scenario under which simple payback period is less than 10 years
250	• 20% reduction in fuel cost
300	• 20% reduction in fuel cost • 10% increase in electricity tariff and 10% reduction in fuel cost
350	• 20% reduction in fuel cost • 20% increase in electricity tariff • 10% increase in electricity tariff and 10% reduction in fuel cost
400	• 20% reduction in fuel cost • 20% increase in electricity tariff • 10% increase in electricity tariff and 10% reduction in fuel cost
450	• 20% reduction in fuel cost • 20% increase in electricity tariff • 10% increase in electricity tariff and 10% reduction in fuel cost
500	• 20% reduction in fuel cost • 20% increase in electricity tariff • 10% increase in electricity tariff and 10% reduction in fuel cost

Table 7.3 Conditions for achieving simple payback period less than 10 years

8.0 RECOMMENDATIONS

The main findings and recommendations resulting from this feasibility study are summarized below.

- Data collected from hotels provide a good correlation between the hotel size (number of guest rooms) and the electrical power demand, heat (steam) demand and the cooling demand.
- The main heat demand in hotels is during the day time when the laundry is in operation (on average about 12 hours per day).
- Therefore, tri-generation systems in hotels would effectively be able to operate only during the day time.
- Although a number of possible tri-generation systems are available, based on the electrical power and heat demand of hotels and other factors such as the availability of fuel, the most suitable system would be the internal combustion engine generator.
- In tri-generation system, the waste heat from the exhaust could be used to generate steam (including for the production of hot water) while the jacket cooling system can be used to produce hot water to operate absorption chillers.
- Based on the heat and power demand of hotels, power matching is found to be the best strategy to optimize tri-generation systems.
- However, data indicates that tri-generation is not economically feasible as the cost of operating such a system is higher than the current cost of steam generation and purchase of electricity from the grid.
- The main reasons for the non-viability of tri-generation are:
  (a) currently steam is generated in boilers using furnace oil which is about 15% cheaper than diesel or heavy fuel oil required to operate an electrical power generator, and
  (b) grid electricity tariff is approximately 30% of the cost of electricity generation using an electric power generator based on the present cost of fuel.
- Although it would be possible to install new generator units which can operate on heavy fuel oil which is about 13% cheaper than diesel, this is not recommended for hotels due to the high noise levels (more than 120 dBA) and vibration levels associated with such generators. Such generators are generally available only for larger size units with capacity over 1000 kVA. In addition, the simple payback period for the additional cost of a new generator (operating on heavy fuel oil) based on fuel cost savings is about 5 years, making this option not viable.
- A sensitivity analysis conducted for varying fuel and electricity costs show that tri-generation system may become financially viable in the future (based on a simple payback period of 10 years).
- Summary of findings of the sensitive analysis are as follows:
  (a) Not feasible in general for hotels with 200 or less guest rooms
  (b) Feasible for hotels with 250 to 300 rooms if fuel price reduces by 20%

(c) Feasible for hotels with more than 300 rooms if fuel price reduces by 20% or if electricity tariff increases by 20% or a combination of a minimum reduction in fuel cost of 10% and electricity tariff increase of 10%.

- Therefore, it is recommended for hotels to consider implementing tri-generation systems in the future if the cost of electricity and fuel vary such that any of the above criteria are met.

APPENDIX – CASHFLOW ANALYSIS

Cashflow analysis for 150 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		21,133,912	21,133,912	21,133,912	21,133,912	21,133,912	21,133,912	21,133,912	21,133,912	21,133,912	21,133,912
Annual savings	15% reduction in fuel cost	(628,044)	(1,256,089)	(1,884,133)	(2,512,177)	(3,140,222)	(3,768,266)	(4,396,310)	(5,024,355)	(5,652,399)	(6,280,443)
	20% reduction in fuel cost	1,010,776	2,021,551	3,032,327	4,043,102	5,053,878	6,064,653	7,075,429	8,086,204	9,096,980	10,107,755
	15% increase in electricity tariff	(1,204,360)	(2,408,720)	(3,613,080)	(4,817,440)	(6,021,799)	(7,226,159)	(8,430,519)	(9,634,879)	(10,839,239)	(12,043,599)
	20% increase in electricity tariff	242,355	484,710	727,064	969,419	1,211,774	1,454,129	1,696,483	1,938,838	2,181,193	2,423,548
	5% reduction in fuel cost and 10% increase in electricity tariff	(1,012,255)	(2,024,509)	(3,036,764)	(4,049,019)	(5,061,274)	(6,073,528)	(7,085,783)	(8,098,038)	(9,110,292)	(10,122,547)
	10% reduction in fuel cost and 10% increase in electricity tariff	626,565	1,253,130	1,879,695	2,506,261	3,132,826	3,759,391	4,385,956	5,012,521	5,639,086	6,265,651

Cashflow analysis for 200 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		25,140,997	25,140,997	25,140,997	25,140,997	25,140,997	25,140,997	25,140,997	25,140,997	25,140,997	25,140,997
Annual savings	15% reduction in fuel cost	83,525	167,049	250,574	334,098	417,623	501,147	584,672	668,197	751,721	835,246
	20% reduction in fuel cost	2,256,087	4,512,174	6,768,261	9,024,348	11,280,435	13,536,523	15,792,610	18,048,697	20,304,784	22,560,871
	15% increase in electricity tariff	(602,300)	(1,204,600)	(1,806,900)	(2,409,200)	(3,011,499)	(3,613,799)	(4,216,099)	(4,818,399)	(5,420,699)	(6,022,999)
	20% increase in electricity tariff	1,341,654	2,683,309	4,024,963	5,366,618	6,708,272	8,049,927	9,391,581	10,733,236	12,074,890	13,416,545
	5% reduction in fuel cost and 10% increase in electricity tariff	(373,692)	(747,383)	(1,121,075)	(1,494,767)	(1,868,459)	(2,242,150)	(2,615,842)	(2,989,534)	(3,363,226)	(3,736,917)
	10% reduction in fuel cost and 10% increase in electricity tariff	1,798,871	3,597,742	5,396,612	7,195,483	8,994,354	10,793,225	12,592,096	14,390,966	16,189,837	17,988,708

Cashflow analysis for 250 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		32,773,249	32,773,249	32,773,249	32,773,249	32,773,249	32,773,249	32,773,249	32,773,249	32,773,249	32,773,249
Annual savings	15% reduction in fuel cost	838,770	1,677,540	2,516,310	3,355,080	4,193,850	5,032,620	5,871,390	6,710,160	7,548,930	8,387,700
	20% reduction in fuel cost	3,554,460	7,108,920	10,663,380	14,217,839	17,772,299	21,326,759	24,881,219	28,435,679	31,990,139	35,544,598
	15% increase in electricity tariff	37,785	75,570	113,355	151,140	188,926	226,711	264,496	302,281	340,066	377,851
	20% increase in electricity tariff	2,486,480	4,972,960	7,459,440	9,945,920	12,432,400	14,918,880	17,405,360	19,891,840	22,378,320	24,864,800
	5% reduction in fuel cost and 10% increase in electricity tariff	304,780	609,560	914,340	1,219,120	1,523,900	1,828,681	2,133,461	2,438,241	2,743,021	3,047,801
	10% reduction in fuel cost and 10% increase in electricity tariff	3,020,470	6,040,940	9,061,410	12,081,880	15,102,350	18,122,819	21,143,289	24,163,759	27,184,229	30,204,699

Cashflow analysis for 300 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		38,701,018	38,701,018	38,701,018	38,701,018	38,701,018	38,701,018	38,701,018	38,701,018	38,701,018	38,701,018
Annual savings	15% reduction in fuel cost	1,690,892	3,381,784	5,072,676	6,763,568	8,454,460	10,145,352	11,836,244	13,527,136	15,218,028	16,908,920
	20% reduction in fuel cost	4,959,094	9,918,188	14,877,281	19,836,375	24,795,469	29,754,563	34,713,656	39,672,750	44,631,844	49,590,938
	15% increase in electricity tariff	769,095	1,538,190	2,307,285	3,076,380	3,845,475	4,614,570	5,383,666	6,152,761	6,921,856	7,690,951
	20% increase in electricity tariff	3,730,031	7,460,062	11,190,093	14,920,125	18,650,156	22,380,187	26,110,218	29,840,249	33,570,280	37,300,311
	5% reduction in fuel cost and 10% increase in electricity tariff	1,076,361	2,152,721	3,229,082	4,305,443	5,381,804	6,458,164	7,534,525	8,610,886	9,687,247	10,763,607
	10% reduction in fuel cost and 10% increase in electricity tariff	4,344,562	8,689,125	13,033,687	17,378,250	21,722,812	26,067,375	30,411,937	34,756,500	39,101,062	43,445,625

Cashflow analysis for 350 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		41,376,585	41,376,585	41,376,585	41,376,585	41,376,585	41,376,585	41,376,585	41,376,585	41,376,585	41,376,585
Annual savings	15% reduction in fuel cost	2,533,491	5,066,981	7,600,472	10,133,963	12,667,453	15,200,944	17,734,434	20,267,925	22,801,416	25,334,906
	20% reduction in fuel cost	6,363,589	12,727,178	19,090,767	25,454,355	31,817,944	38,181,533	44,545,122	50,908,711	57,272,300	63,635,889
	15% increase in electricity tariff	1,485,230	2,970,460	4,455,690	5,940,920	7,426,150	8,911,380	10,396,610	11,881,840	13,367,070	14,852,300
	20% increase in electricity tariff	4,965,908	9,931,816	14,897,724	19,863,632	24,829,540	29,795,448	34,761,356	39,727,264	44,693,172	49,659,081
	5% reduction in fuel cost and 10% increase in electricity tariff	1,834,650	3,669,300	5,503,951	7,338,601	9,173,251	11,007,901	12,842,552	14,677,202	16,511,852	18,346,502
	10% reduction in fuel cost and 10% increase in electricity tariff	5,664,748	11,329,497	16,994,245	22,658,994	28,323,742	33,988,491	39,653,239	45,317,988	50,982,736	56,647,485

Cashflow analysis for 400 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		45,048,964	45,048,964	45,048,964	45,048,964	45,048,964	45,048,964	45,048,964	45,048,964	45,048,964	45,048,964
Annual savings	15% reduction in fuel cost	2,728,166	5,456,332	8,184,497	10,912,663	13,640,829	16,368,995	19,097,160	21,825,326	24,553,492	27,281,658
	20% reduction in fuel cost	7,129,545	14,259,090	21,388,635	28,518,181	35,647,726	42,777,271	49,906,816	57,036,361	64,165,906	71,295,451
	15% increase in electricity tariff	1,547,790	3,095,580	4,643,370	6,191,160	7,738,950	9,286,740	10,834,530	12,382,319	13,930,109	15,477,899
	20% increase in electricity tariff	5,555,711	11,111,421	16,667,132	22,222,843	27,778,553	33,334,264	38,889,975	44,445,685	50,001,396	55,557,107
	5% reduction in fuel cost and 10% increase in electricity tariff	1,941,249	3,882,497	5,823,746	7,764,994	9,706,243	11,647,491	13,588,740	15,529,988	17,471,237	19,412,485
	10% reduction in fuel cost and 10% increase in electricity tariff	6,342,628	12,685,256	19,027,884	25,370,512	31,713,140	38,055,767	44,398,395	50,741,023	57,083,651	63,426,279

Cashflow analysis for 450 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		51,827,922	51,827,922	51,827,922	51,827,922	51,827,922	51,827,922	51,827,922	51,827,922	51,827,922	51,827,922
Annual savings	15% reduction in fuel cost	3,551,717	7,103,435	10,655,152	14,206,870	17,758,587	21,310,305	24,862,022	28,413,740	31,965,457	35,517,175
	20% reduction in fuel cost	8,533,763	17,067,525	25,601,288	34,135,050	42,668,813	51,202,576	59,736,338	68,270,101	76,803,863	85,337,626
	15% increase in electricity tariff	2,233,575	4,467,150	6,700,724	8,934,299	11,167,874	13,401,449	15,635,024	17,868,599	20,102,173	22,335,748
	20% increase in electricity tariff	6,776,239	13,552,478	20,328,717	27,104,956	33,881,195	40,657,434	47,433,673	54,209,912	60,986,151	67,762,390
	5% reduction in fuel cost and 10% increase in electricity tariff	2,672,956	5,345,911	8,018,867	10,691,823	13,364,779	16,037,734	18,710,690	21,383,646	24,056,601	26,729,557
	10% reduction in fuel cost and 10% increase in electricity tariff	7,655,001	15,310,002	22,965,002	30,620,003	38,275,004	45,930,005	53,585,006	61,240,007	68,895,007	76,550,008

Cashflow analysis for 500 room Hotels (tri-generation)

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Investment		57,958,591	57,958,591	57,958,591	57,958,591	57,958,591	57,958,591	57,958,591	57,958,591	57,958,591	57,958,591
Annual savings	15% reduction in fuel cost	4,365,746	8,731,492	13,097,237	17,462,983	21,828,729	26,194,475	30,560,220	34,925,966	39,291,712	43,657,458
	20% reduction in fuel cost	9,937,841	19,875,682	29,813,524	39,751,365	49,689,206	59,627,047	69,564,889	79,502,730	89,440,571	99,378,412
	15% increase in electricity tariff	2,904,185	5,808,369	8,712,554	11,616,739	14,520,923	17,425,108	20,329,293	23,233,477	26,137,662	29,041,847
	20% increase in electricity tariff	7,989,093	15,978,186	23,967,279	31,956,372	39,945,466	47,934,559	55,923,652	63,912,745	71,901,838	79,890,931
	5% reduction in fuel cost and 10% increase in electricity tariff	3,391,372	6,782,743	10,174,115	13,565,487	16,956,859	20,348,230	23,739,602	27,130,974	30,522,345	33,913,717
	10% reduction in fuel cost and 10% increase in electricity tariff	8,963,467	17,926,934	26,890,402	35,853,869	44,817,336	53,780,803	62,744,270	71,707,737	80,671,205	89,634,672