TRIGENERATION - A GREEN APPROACH FOR MEETING TOTAL BUILDING SERVICE REQUIREMENT

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Abstract: Tourism industry in the country is presently seeing a considerable growth, with demand for hotel and accommodation industry to keep pace. In expanding this sector, provision of electricity and other utilities is essential. In this regard, the availability of electricity supply and the quality of available power are serious concerns when it comes to expanding the facility to remote but attractive areas. As a means of handling this situation, in this paper the possibility of using stand alone trigeneration to meet heating, cooling and electricity demand of such facilities is explored and compared with the present system of grid connected power and diesel based heat generation. A comparison of the two systems; trigeneration and present base case scenario, reveals that there will be over 50% reduction in CO_2 emission and about 41% saving in energy bills over those of base case when a trigeneration system is sized based on the criterion of meeting total cooling demand using vapour absorption refrigeration. A simple payback estimates shows that recovery of investment for trigeneration system is well under two years.

Keywords: cogeneration, trigeneration, absorption refrigeration, air-conditioning, CO_2 emission

1. Introduction

Growth in tourism industry demands improvement in necessary infrastructure facilities such as accommodation, transportation. Accommodation with standard facilities such as restaurants and other recreation aspects is one important factor that affects the visitor numbers. When trying to expand and improve accommodation facilities in remote but attractive areas, availability and quality of electricity supply are serious concerns where preference in many new cases to have an independent source of power supply such as a diesel generator.

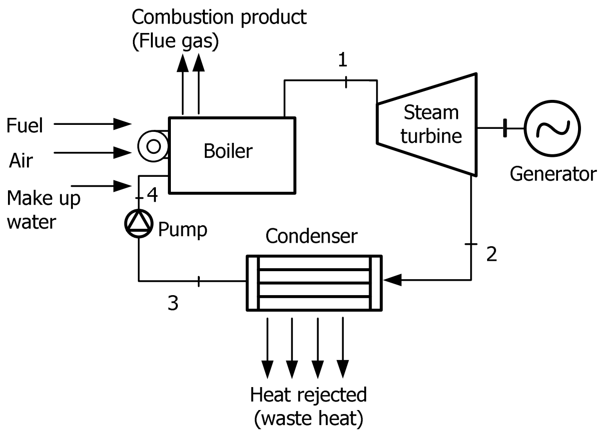
In general, hotel facilities that plan to attract visitors need maintaining certain level facilities where making available of utilities such as lighting, air conditioning, hot water and low-pressure steam (< 5 bar) are essential. In the present practice, majority of existing service providers use power from national grid to run vapour compression chillers to produce required comfort air conditioning, and operate low pressure boilers to meet the steam and hot water demand. In doing so, these facilities use two sources of energy; electricity for running air conditioning machinery and another fuel (diesel, gas or fuel oil, biomass etc.) to run the boilers.

The above indicated end use of energy provides an opportunity for integration of the mechanisms to obtain the required utility services (cooling, heating and power) based on a single source of energy. This paves the way for cogeneration, trigeneration or polygeneration depending on how the scheme of energy use are planned and how the waste energy from one step is utilized in another. Such planning of the use energy resources certainly contributes to cutting down the carbon dioxide emission and reduced energy bills for the industry concern. Based on above background of timely need in the country, this paper evaluates the energy cost and benefits of trigeneration using the latest technologies of steam turbines, boilers and LiBr+H_2O absorption chiller.

2. Theoretical background

2.1 Steam power plant

Steam turbines or gas turbines are the usual prime movers in fossil fuel or biomass based power plants. In cyclic operation, these systems generally rejects considerable amounts of thermal energy in the form of latent heat of steam being condensed or thermal energy in high temperature combustion products. Fig 1 shows a schematic diagram of main hardware assembly of a stem power plant system and Rankine cycle (with superheat), which represents the thermodynamic cycle for a conventional steam power plant on a property plane.



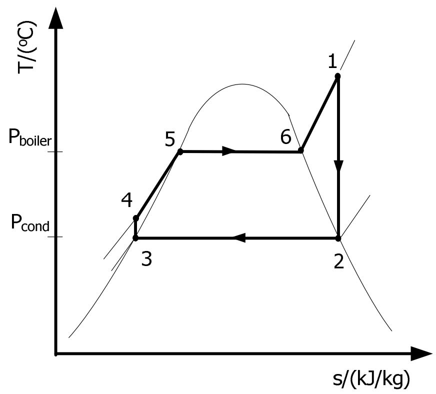


Fig 1 – Schematic diagram of hardware arrangement of a steam power plant (left) and Rankine cycle (with superheat) on temperature - entropy (T-*s*) plane (right)

In Fig 1, process 1-2 produce useful work that drives an electricity generator to produce electric power, whereas process 2-3 is where the waste heat from the system is dumped to the environment. The amount of heat or work interactions of these processes could be estimated using the first law of thermodynamics. In a cogeneration perspective, the waste heat at the condenser is the useful product. In general, the efficiency of steam power plants vary in the range 25 % to 45%, which to a greater extent depend on the operating parameters of the power plant, number of turbine stages, the capacity and the fuel etc [1, 2]. To elaborate on this aspect, Fig 2 presents a general picture of how the selection of operating parameters of the steam cycle affect heat output and efficiency for a unit work output, where Pc is the condenser pressure .

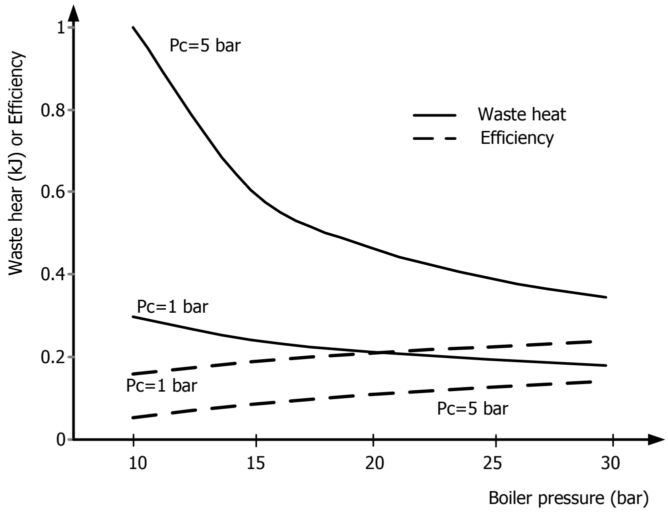


Fig 2 - Effect of main operating pressures on the heat output and efficiency of steam power plants (generated using REFPROP [3] based on Rankine cycle with superheat)

2.2 Heat driven refrigeration

Absorption refrigeration cycle is similar to the vapour compression refrigeration cycle in certain respects. However, when compared with vapour compression cycle, the absence of an electrically driven compressor and the presence of two fluids (refrigerant and absorber) in place of a single refrigerant are the main differences of absorption refrigeration cycle. Fig 3 shows the essential components of a vapour absorption refrigeration system, where the heat supplied to the boiler drives out the refrigerant from refrigerant and absorber mixture. Since absorption cycle is a heat activated thermal cycle, it exchange heat with surroundings with no appreciable input of mechanical energy, and any source of heat, including low-temperature waste heat can be used as the source of thermal energy.

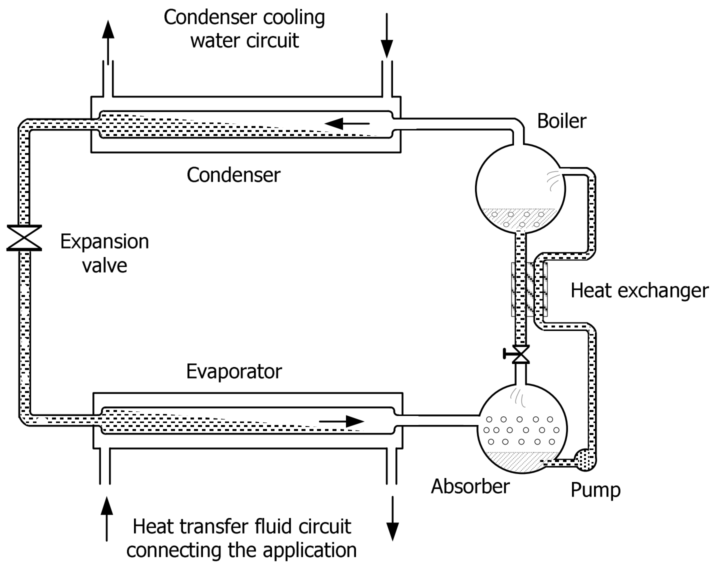


Fig 3 – The essential components of the vapour absorption system [4]

The working fluids in absorption systems achieve their intended cycle functions by undergoing phase change. For known combinations of refrigerants and absorbers, over pressure ranges of interest, $Q_{evp} \approx Q_{cond}$ and $Q_{boiler} \approx Q_{absorber}$ as the latent heat of evaporation and condensation are relatively constant when operating further away from the critical point [5]. This refers to relatively lower cooling coefficient of performance (COP) of absorption system (COP = Q_{evp}/Q_{boiler}) in comparison with vapour compression systems, where Q_{evp} is the amount of heat absorbed at the evaporator and Q_{boiler} is the amount of heat added at the boiler.

Two common refrigerant, absorber combinations in common use are water and lithium bromide (LiBr), and ammonia and water. In the case of LiBr and water mixture, water is the refrigerant and this combination is commonly used for producing chilled water at temperatures above 3 ^{o}C [6], mainly for air conditioning applications. In the case of water and ammonia combination, ammonia being the refrigerant, it is possible to achieve temperatures below 0 ^{o}C for industrial applications such as making block ice, where temperatures below – 10 ^{o}C is the requirement.

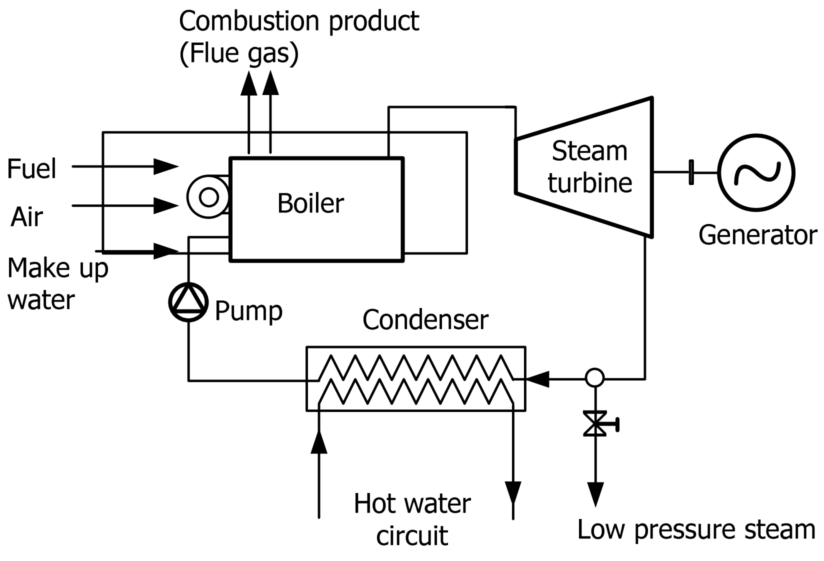
In the context of the theme of this article, the LiBr and water combination is the suitable working fluids for absorption systems to be used in utilizing waste heat to produce comfort air conditioning in industrial applications.

2.3 Cogeneration or Trigeneration to meet end user demand

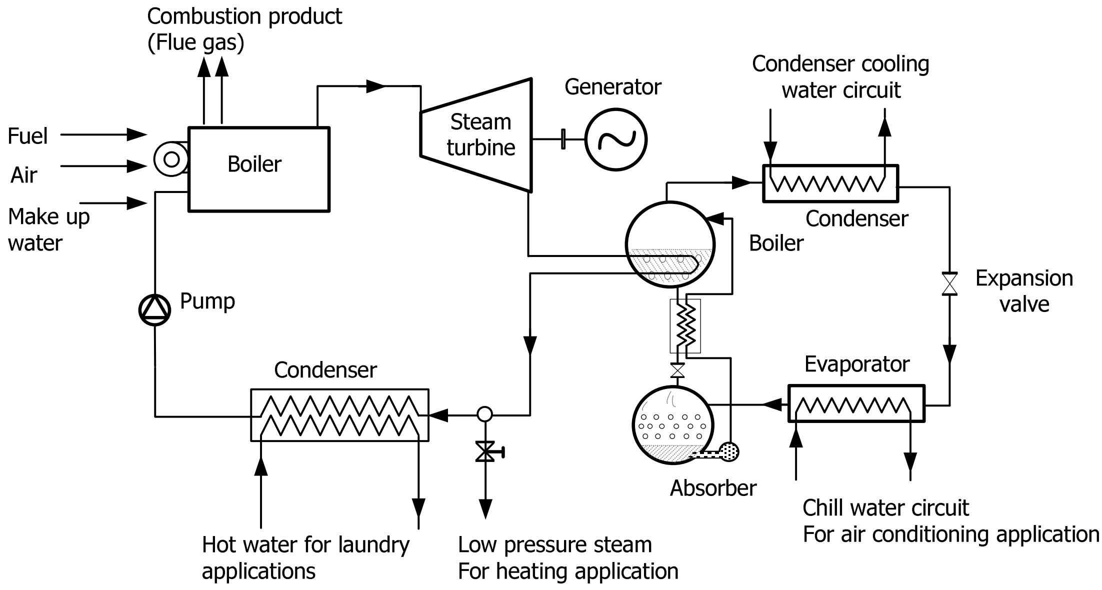
In many cases of power plant system, in a carefully thought, well planned energy application, at least part of the thermal energy in the waste stream could be recovered for useful purposes. The present day technologies allow generating power as well as use of waste heat in meeting heating demands of the end users, enhancing the overall energy conversion efficiency by a considerable degree. Main benefits of cogeneration are lower consumption of primary energy and associated low energy bills, no or reduced transmission and distribution losses, less burden on national grid and less environmental pollution [7]. The content of this section mainly discuss steam power plants associated cogeneration concepts.

When considering the end user's requirements, for the selected industry concerned, it makes more sense to use cogeneration or trigeneration plants to meet the service requirements of electricity, cooling and heating. When the waste heat from steam power plant is available in a temperature range 150 ~ 200 ^{o}C, for an application that need specified amounts of electricity, air conditioning and heating (hot water and steam), a cogeneration system or a trigeneration system could be planned to completely meet one, two or all three aspects above.

Fig 4 presents possible cogeneration and trigeneration schemes that suits an application requiring power, cooling and heating.



a) Cogeneration system – Power and heat



b) Trigeneration system – Power, cooling and heat

Fig 4 – Schematic diagrams of cogeneration and trigeneration options

2.4 Carbon dioxide emissions from heat and power generation

The saving in emissions and resulting reductions in environmental pollutions is based on the concept of reduced use of fossil fuel when implementing cogeneration concept for an application which use different sources of energy otherwise to meet the heating/cooling and power demands. Table 1 presents emission factors from heat and power generation based on standard power generation technologies. However, these values also depend on the overall efficiency of the plant.

Table 1 – CO_2 emission from electricity and heat generation for different fuels [1, 8, 9]

Fuel	g CO_2/kWh(elect)	g CO_2/kWh(thermal)
Coal	1260	370
Diesel	810	240
Liquefied petroleum gas	650	240
Residual fuel oil	635	260
Natural gas	370	230

2.5 Technology options and costs

Steam turbine technology is a time tested and well established area of power generation field so that manufacturers of steam turbines are found all over the world, covering capacities from few kilowatts to thousands of megawatts. this invariably means one tend to get a number of cost options depending on quality, country of origin, brand and manufacturer etc. Absorption refrigeration technology on the other hand, though time tested and reliable technology, has not developed to a level of global manufacturing as steam turbine industry. Very few manufacturers produce these systems and mostly use manufacture specific component level designs. Table 2 presents present days cost of the two machinery items obtained from manufacturers.

Table 2 - Cost of steam power plants and absorption refrigeration systems

Item	**Price ($/kW)**	**Remarks**
Steam power plant	200 ~ 300	Prices include turbine, generator, controls and tools, Not included installation technical assistance charges, steam piping and insulations, and local installation charges, taxes, VAT etc.
Absorption refrigeration system (LiBr+H_2O)	125 ~ 175	

3. Results and discussion

3.1 Cases compared and discussed

In order to quantify the cost and benefits of trigeneration, a real life application need to be used in estimates and planning so that the situation concerning power consumptions and energy bills could be compared. For this purpose, we consider a hotel of general description given in Table 3, located in a remote part of the country where stand-alone power supply is preferred due to issues of local power quality, interruptions and availability of required capacity.

Lets consider the base case of obtaining power from national grid for running the air conditioners (based on vapour compression chillers) and all other electrical loads including lighting, and diesel fired boiler is used for generating low pressure steam and hot water. Then, as an alternative, lets consider a trigeneration system that has been planned and sized to provide the required air conditioning based on vapour absorption refrigeration using LiBr and water combination.

Table 3 – Details of the selected case for comparison of benefits of trigeneration vs conventional use of energy

Parameter	Value/units	Remarks
Number of rooms	100	Average floor area of a room 500 ft^2
Common areas	30% total room area	Lighting intensity, 1.2 W/ft^2
Outside temperatures		Dry bulb and wet bulb
Day time AC demand	100%	
Night time AC demand	50% of day time demand	
Lighting intensity	1.0 W/ft^2	Based on recommendations of US dept of energy and ASHRAE 90.1-2007 [10]
Kitchen area	5% total room area	
Kitchen lighting	1.2 W/ft^2	Based on recommendations of US dept of energy and ASHRAE 90.1-2007 [10]
Kitchen equipment power	25% of total lighting	
Hot water consumption per room, including laundry needs	50 liter per 24 h	Water at 50 ~ 60 ^oC, obtained through hot water boiler presently
Steam generation	1000 kg/h for 6 ~ 8 hours per day (24 hour)	Based on usage of existing facilities, total steam generation for steam bath, sauna etc, presently generated using diesel, at 7 bar
Boiler house power consumption	40 kW	

The operating pressure of the boiler is selected to be 40 bar, which produce a steam flow rate sufficient to run the absorption chiller after expansion through the turbine where electricity is generated. The steam is first fed to steam turbine and the turbine exit is set to provide sufficient pressure for the chiller as given in Fig 4b. Used steam leaving the chiller is condensed (if necessary) and sent back to boiler. If steam is bled off as low pressure steam, make up water will have to be provided. Table 4 summarizes the two cases

Table 4 – Main operating parameters of the base case and estimated operating parameters of trigeneration system

Parameter	Value	Base case	Trigeneration (Fig 4b)
Air conditioning cooling load	1170 kW	Use vapour compression chillers, COP of the plant 2.25, ancillary loads 10% of compressor load (total estimated load: 580 kW)	Use vapour absorption chillers, steam demand 1255 kg/h, cooling capacity 1163 kW$^\$$
Lighting and other electrical loads	150 kW	Obtained from the grid at Rs. 9.30 per kWh	Obtained through generated power from steam turbine, which is estimated to be 176 kW
Low pressure steam and hot water	1000 kg/h steam	Use a diesel fired boiler of steam generating capacity 1000 kg/h. Diesel cost Rs. 75 per liter	Use condenser heat and exit steam from chiller for hot water and low pressure steam

$^\$$ – Obtained from details of commercially available absorption chiller units, ancillary electricity demand of the chiller is 30 kW

In this instance, the sizing criterion of the trigeneration plant is such that it has been planned to meet the complete air conditioning load. The boiler has been selected to provide required steam flow rate for the chiller, and the power generation corresponds to this mass flow rate of steam which meet the heat requirement of the absorption chiller. The power generated in the steam power plant can be used in house or exported to national grid. In this case the amount of power generated is too small for exportation, however, sufficient to meet electricity demand in house.

3.2 Benefit of trigeneration system

When using the trigeneration system configuration in Fig 4, and emission factors given in Table 2, the estimated fuel cost and carbon emissions from the two power supply schemes are given in Table 5. In arriving at these results, the night time air conditioning demand is assumed to be 50% of that during the day, and the boiler runs at 50% of its capacity during the night.

Table 5 – Daily use of energy of trigeneration system and base case

Parameter	Units	Base case	Trigeneration $$
Total electricity consumption	kWh/24 h	13,031	2,591
Total heat generated, kWh/24 h	kWh/24 h	11,440	17,921
Total fuel used for heat generation	Litre/24 h	532.2	1,888

$$ - Boiler combustion efficiency: 92%, heavy fuel oil fired boiler, density and calorific of fuel oil 950 kg/m3 and 39.2 MJ/kg respectively,

Table 5 presents estimated daily energy use of the two cases considered in the study. In the case of trigeneration, there is only one source of energy; fuel oil, that fuel both modes of energy. This is the very feature of cogeneration which is explored in this example to obtain all three utilities; cooling, heat and electricity, for the facility concern.

Table 6 presents estimated cost of energy for two cases considered as well as the reduction of carbon dioxide emissions when a new facility is planned to take the advantages of trigeneration to meet all the utility services in house. The total energy bill of Rs 4.8 million per month of the base case has reduced to little under Rs 2.0 million per month when trigeneration is used with a sizing criterion of meeting the total air conditioning demand in this example. The other benefit of this attempt is the amount of carbon released to the atmosphere reduces to a half of that of the base case which is a very significant achievement when considered with the saving in energy bills.

Table 6 – Energy cost and carbon emissions of trigeneration system and base case

Parameter	Units	Base case	Trigeneration $$
Total electricity bill	Rs/month	3,635,660	Use in house power
Total oil bill (for heat generation)	Rs/month	1,204,211	1,956,846[£]
Amount of CO_2 released	kg/year	5,026,219[(1)]	2,516,165[(2)]

$$- Price of fuel oil Rs 50 per liter, price of electricity Rs 9.30/kWh, electricity generated in-house used for meeting lighting and other electrical loads

£ - After deducting equivalent electricity cost of lighting and other electrical loads at Rs 9.30 per kWh.

(1) – For diesel based power generation, with CO_2 emission of 810 g/kWh (elect)

(2) – For fuel oil based heat generation, with CO_2 emission of 260 g/kWh (thermal)

4. Concluding remarks

The benefits of using trigeneration in a potential local industry was discussed with estimates based on information obtained from relevant literature and justifiable assumptions. As shown in the results, the concept, if implemented with due planning and equipment sizing in the development of tourism industry or any other similar application, could bring in substantial environmental and financial benefits while reducing the amount of raw energy imported for thermal power generation.

A quick estimate based on 250 $/kW for steam plant and 150 $/kW refrigeration system, and when local tax and installation cost included, the above trigeneration system has an attractive pay back duration of under 2 years depending on the other uncertainties associated.

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