HIGHER EFFICIENCY AND EFFECTIVE USE OF PRIMARY FUEL USINGCOMBINED HEAT AND POWER

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Abstract -The use of electricity and heat are essential in our daily life activities. They areused domestically for heating, lighting, washing, cooling, and cooking. Commercially, it is used in transportation, heating, cooling, manufacturing and processing. In view of this, there is the need to use energy (electricity and heat) efficiently to reduce the waste from energy such as heat and CO_2 released into the atmosphere. The efficient use of energy makes the environment safe and maintains a high quality of lives of people.

The majority of electricity generated in the world today is from thermal, which has a low efficiency ranging between 30-37% and combines cycle gas turbine (CCGT) having approximately 47%. A high percentage of the primary fuel used to generate power is converted to waste as heat into the environment. Therefore, the need arises to recover the heat and used for another purpose to enhance efficiency. To attain higher efficiency and effective use of primary fuel, Combined Heat and Power (CHP) is employed in recovering of waste heat to be reused, therefore, increasing productivity.

This paper highlights the working principles, application, factors influencing the selection of CHP and economic importance of installing CHP. It further uses a Salford hospital as a case study to explain the economic benefits of installing CHP.

Keywords: energy, waste, electricity, heat, fuel, power.

1. INTRODUCTION

Energy forms part of the basics in our everyday life activities. Energy is used for both domestic and commercial purpose. Domestically it is used for cooking, heating, cooling, and lighting. Also on the commercial level, it is used for transportation, heating, cooling, manufacturing and processing [1,2]. The waste from energy creates damages to the environment resulting in climate change and global warming. To make the environment friendly and maintain the quality of lives there is the need to use energy efficiently to mitigate these challenges [2].

Most of the world electricity is generated from thermal generation using heat to create high-pressuresteamto drive a turbine to produce electricity. The majority of thetraditionalthermalgenerationplanthave an efficiencyranging between 30-37% whiles combinescycle gas turbine (CCGT) hasapproximately 47% efficiency[3]. It isestimatedthat more than 50% of theprimaryenergyisnotconvertedintoelectricity but wasted; whichisreleasedintotheenvironment as heatand carbon dioxide (CO_2) makingtheenvironmentunsafe. Thislowefficiencyis as a result of irreversibility of theprocess[3]therefore, it willbewisetoreclaimthewasteheat in thegenerationprocessand put it intousehencetheneedto combinetheprocess of electricalgenerationandheatproduction. In view of this, theneedarisestousehighlyefficientcombinedheatandpower (CHP) to curb theseproblems.

2. COMBINED HEAT AND POWER (CHP)

CHP also known as cogenerationis the idea of combining electrical power generation and heat production process to generate electricity and heat from a single fuel source [3]. During CHP process of generating electricity, waste heat is recovered by the use of heat exchange from sources such as exhaust gases. The use of CHP increases the overall efficiency of the system to 75% or moreif well optimized, as compared to an average of 34% for a conventional thermal power plant [4]. CHP system is made up of a prime mover (engine), generator, waste heat recovery system, control system and exhaust system [5].
The application of CHP concept helps improve energy efficiency of the system and reduce the release of CO_2 into the atmosphere. Modern CHP technologies make it possible to employ the use of multiple fuel types [6]. This makes the use of such systems flexible, ensure fuel security andprevents price volatility. The efficiency of CHP depends much on the technology applied and primary energy source employed [6]. The size of cogeneration systems size in terms of electrical power output ranges from 1kWe (kilowatt electric) to over 500 MWe (megawatt electric) [6].

2.1.How CHP works

CHP is an integrated energy system that produces electricity and heat at the same time from a single fuel. There are two types of cogeneration process namely “topping” and “bottoming cycle”. Bottom cycle process produces useful heat as the main product through the combustion of fuel. Some of the heat that are lost through the exhaust is recoveredto generate power [7]. On the other hand, in topping cycle process the fuel is used to generate electricity first and the waste heat isretrieved to produce useful thermal energy [7]. The prime mover of CHP through the process of combustion produces mechanical power to drive the shaft of the generator. The types of fuel which are mainly used in the combustion process is coal, oil, diesel, solid waste, and natural gas (NG) of which NG is mostly used recently [6]. The energy in the fuel is released as heat by burning them in a furnace. The energy generated is used to boil water to produce steam, which is pressurized and expanded across the turbine to drive the generator to produce electricity [8]. The hot gas (steam) after turning the turbine passes through the system's exhaust. The heat in the steam through the exhaust is recovered by the heat exchanger and transferred to a boiler. The steam is cooled to water after the exchange and it is pumped back to repeat the cycle.

2.2.Application of CHP

The classification of CHP is based on the types of application, fuel and prime mover used. Generally, CHP is used to generate electricity and heat [6]. The ratio of heat to power needed in various buildings varies depending on its use, therefore, CHP are sized to meet the base heat demand of the building[6,3]. If there is an additional need for electricity it is supplied from the utility grid or when there is an excess of electricity it can be export to the grid [3]. Utilization of "waste" heat is essential in CHP therefore the overall efficiency of the system will be low if the recovery process is not effective. In view of this CHP is install in buildings that demand heat all-year round. Examples of such buildings are leisure centers, swimming pools, hostels, hospital, and residential establishments. Buildings like offices, which have a cooling load, at most of the times of the year are unsuitable for the installation of the cogeneration system [3].

3. FACTORS THAT INFLUENCE THE SELECTION OF CHP

A lot of factors are considered when considering the viability of CHP system. An initial feasibility study is done before the installation of CHP system; the study is done to estimate the cost saving and financial returns upon installing the suitable cogeneration plant [10]. In addition, the time taken to recoup cost of installation of CHP should be investigated. Also, the study should determine the site conditions to know if it is conducive to install the plant [4]. The efficiency of all loads in the building should be high to ensure the appropriate system capacity sizing before considering the use of CHP [4].

3.1. Thermal and electrical requirement

It is essential to understand the buildings thermal and electrical requirement when installing CHP system [4][11]. Since cogeneration generates both heat and electric power simultaneously, the facility's electrical power and thermal daily, weekly, seasonal and future needs are assessed. This is assessed by collecting past consumption data from the site utility bills. The data can be used to predict the future consumption of the building [10]. Energy demand of most facilities are not static but changes over the period as a result of addition of needed equipment or changes in the demand for old ones. Therefore, it is necessary to consider anticipated immediate demand in sizing CHP plant [10].

Despite considering the electricity and heat demand of the building, it is practical and economical to size the system to meet the base heat demand of the facility. Oversizing of the system will lead to the wastage of recovered thermal energy- resulting in low efficiency and energy bills savings of the system [4].

3.2. Operating hours of the facility

It is important to consider the operating hours of the facility. It is vital to consider the duration in which the facility will use the output of CHP system. It is desirable for CHP system to run for longer hours at high efficiency [4,10]. It is estimated that to achieve payback of the cost of three (3) to four (4) years after installing CHP system, the system should operate for approximately ranging between 4500 to 6000 hours per year that it is necessary to operate it for 12.3 to 16.5 hour per day for a year[3].

3.3. Economic Factor

Economic factor is one of the factors to be looked at when considering the installation of CHP plant. Firstly, the electricity and fuel cost of the building should be known [11]. This is achieved by reviewing the site energy consumption over a period mostly twelve (12) months [10,11]. Also, the operational and capital cost of CHP system should be determined and compared to the facility's consumption rate. The operational and capital cost of cogeneration plant is significantly higher than that of the traditional boilers [3]. It is very instrumental to investigate the payback period after the installation of CHP system. The result is the basis to determine if the installation of CHP system is economically favorable. The payback period is mostly between three (3) to seven (7) years and depends on the capital cost per kW, CHP overall efficiency and how long the system will be operating [4].

In addition, the spark spread is one of the key factors to determine the economic favorability when considering the installation of CHP plant [4]. The annual average cost of gas in $/MMBtu is compared to the annual average electricity cost in $/MMBtu to find the spark spread. Spark spread refers to the price difference between the cost of electricity and fuel of the facility [11]. If the spark speed of CHP is greater than $12/MMBtu then the system has great potential for favorable payback [11].

Again, the cost of synchronizing the CHP system the utility grid should also be considered. The cost mainly involves the installation of electrical switches and sometimes exportmeters [3]. Itis therefore economically viable if the retail electricity price is high but the cost of running the CHP unit in generating electrical power is relatively low [4]. If this is not the case then it is economically sound to size the unit to meet the base electrical load. Another factor that should be considered is the dimension and weight of the plant and the facility space available [10].

4. SELECTING PRIME MOVER FOR CHP PLANT

When data on energy and cost have been collected, the next step is to select a suitable CHP system. The type of prime mover for CHP plant is one of the main factors considered. The criteria that are factored into account when choosing a prime mover for CHP plant are; operating hours, maintenance requirement, type of fuel required and the capacity limit.

4.1 Steam turbines

This type of prime mover is suitable when the electrical base load of the facility is 250 kWe or more and the facility has a ratio of heat to power demand ranging from 3:1 to 10:1. Also, steam turbines are appropriate when there is an availability of relatively cheap fuel, least mechanical maintenance needed and sufficient plot space [10,3].

4.2 Steam turbines

In most cases gas turbines are suitable if there is a continuous demand of power with 3:1 heat to power ratio and the facility has an electric power load greater than 1MWe [10]. Again, gas turbine is fitting when there is the availability of natural gas, high demand for high or medium pressurized gas and the need for less frequent maintenance [10].

4.3 Reciprocity engine generators

Reciprocity engines are appropriate if there is non-continuous power demand; the electrical load is less than 1MWe and when low-pressure steam is demanded. Also at sites where Natural gas (NG) is not available and the heat to power demand ratio is low reciprocity engines are suitable [10]. The prime mover requires constant change of oil and filter hence high maintenance.

5. BENEFITS OF INSTALLING CHP

The increase in CHP systems at homes and industries has environmental and economic benefits. The main environmental benefit of using CHP systems is the reduction of emission of CO_2 and other harmful gases including nitrogen oxide and Sulphur dioxide [4,12]. For instances, it can be estimated that a gas turbine CHP plant with capacity of 5MW and 75 percent overall efficiency caused 50 percent reduction in the release of CO_2 into the atmosphere as compared to natural gas boiler and a generator that uses fossil fuel with 80 percent efficiency. Following the above estimation CHP systems are capable of reducing the emission of CO_2 by approximately 4,000 metric tons per MW [4].

Secondly, reduction of energy cost is the main economical factor in the installation of CHP systems. When CHP unit is properly sized it provide lower energy cost as compared to the cost of electricity by utility companies and boiler fuel cost [12]. In clean energy solution report by environmental protection agency (EPA) U.S. published in August 2012, it was estimated that with the installation of 40GW of CHP, energy users will save $10 billion a year in relation to the existing energy sources used [12]. Also, employing the use of CHP in energy intensive industries such as food and drink manufacturing industries may save approximately 40% of their energy bills and also reduce carbon emission significantly. CHP may be used in conjunction with an absorption chiller, to provide refrigeration, heat, and electricity. This process is called combined cooling, heat, and power (CCHP) or Trigeneration

6. CASE STUDY

The case study is based on the Christie unit in Salford royal NHS foundation trust. Christie unit is a specialist center at Salford hospital, which is part of a unique network of radiotherapy centers. It is established to treat cancer patients from Salford, Wigan and Bolton in the UK [13].

In order for the building to meet the mandatory building regulations, the building demands very high energy therefore, there is the need to produce heat and power at high efficiency to meet the facility demand. The site has annual electricity and heat demand of 430,578kWh and 186,071kWh respectively. The annual gas consumption is 232,589kWh with electricity and gas prices for 88% are 11.5667p/kWh and 3.1208p/kWh respectively. Also, electricity and gas price for the remaining 12% are 10.3362p/kWh and 2.7888p/kWh respectively. A 15kWe/30kWth loadTracker CHP is installed to supply 92 percent of the site heat demand and 20 percent of electrical demand [14]. If CHP is installed to replace the conventional separate system how much energy cost is saved per year.

<u>CHP data [5]:</u>
Electrical output=15kW
Thermal output = 30KW
Electrical efficiency = 30%
Thermal efficiency = 62%
Overall efficiency (η)= 92%
Fuel = natural gas, propane, butane
Considering the two options as follows;

<u>Using the conventional system</u>:
Data:
Annual electricity demand (E_D)= 430,578kWh
Heat demand (H_D) =186,071kWh
Gas Consumption (G_c) = 232,589kWh
If the number of hours in the year (N_{hr}) = 8760hr,
Electricity demand per hour (E_{Dh}),

$$\frac{E_D}{N_{hr}} = \frac{430{,}578}{8760} = 49.2kW$$

Heat demand per hour (H_{Dh}), $\frac{H_{Dh}}{N_{hr}} = \frac{186{,}071}{8760} = 21.2kW$

The cost of electricity per hour (88%) in £= $\frac{0.88 \times 49.2 \times 11.5667}{100} = £5$

The cost of electricity per hour (12%) in £= $\frac{0.12 \times 49.2 \times 10.3362}{100} = £0.6$

The total cost of electricity per hour = 5 + 0.6 =£5.6

The total cost of electricity per year = 5.6 × 8760 = £49,056

The amount of gas consumer per hour = $\frac{G_c}{N_{hr}} = \frac{232{,}589}{8760} = 26.55kW$

The cost of gas per hour (88%) = $\frac{0.88 \times 26.55 \times 3.1208}{100} = £0.73$

The cost of gas per hour (12%) = $\frac{0.12 \times 26.55 \times 2.7888}{100} = £0.089$

The total cost of gas per hour = 0.73 + 0.089 = £0.82

The total cost of gas per year = 0.82 × 8760 = £7,183.2

The total energy cost for an hour of operation = 5.6 + 0.82 = £6.42

The total energy cost for a year of operation = 6.42 × 8760 = £56,239.2

Using CHP system:

If CHP supplies 92 percent of the site total heat demand,

Therefore, the heat supplied by CHP = $0.92 \times H_{Dh} = 0.92 \times 21.2 = 19.5kW$

If CHP supplies 20 percent of the site total electricity demand,

Therefore, the electricity supplied by CHP = $0.2 \times H_{Dh} = 0.2 \times 49.2 = 9.84kW$

Total energy supplied by CHP = $19.5 + 9.84 = 29.34kW$

Fuel power input to CHP system = $\frac{29.34}{\eta} = \frac{29.34}{0.92} = 31.9kW$

The cost of gas per hour (88%) = $\frac{0.88 \times 31.9 \times 3.1208}{100} = £0.88$

The cost of gas per hour (12%) = $\frac{0.12 \times 31.9 \times 2.7888}{100} = £0.107$

The remaining electricity (80%) is supplied by the conventional system:

Therefore, the remaining amount of electricity supplied = 49.2 – 9.84 = 39.36kW

The cost of electricity per hour (88%) = $\frac{0.88 \times 39.36 \times 11.5667}{100} = £4$

The cost of electricity per hour (12%) = $\frac{0.12 \times 39.36 \times 10.3362}{100} = £0.5$

The remaining heat energy (8%) is supplied by the conventional system.

Also, the cost of gas per hour (88%) = $\frac{0.08 \times 0.88 \times 26.55 \times 3.1208}{100} = £0.06$

The cost of gas per hour (12%) = $\frac{0.08 \times 0.12 \times 26.55 \times 2.7888}{100} = £0.007$

Total cost of electricity per hour = 4 +0.5 = £4.5

Total cost of electricity per year = 4.5 × 8760 = £39,420

Total cost of gas per hour = 0.88 + 0.107 + 0.06 + 0.007 = £1.054

Total cost of gas per year = 1.054 × 8760 = £9,233.04

The total energy cost for an hour of operation = 4.5 + 1.054 = £5.554

The total energy cost for a year of operation = 5.554 ×8760 = £48,653.04

5. RESULT AND DISCUSSION

Table 1. Cost of saving at the hospital for a year in £

	Conventional	CHP	Cost saving
Cost of Electricity	£49,056	£39,420	-------
Cost of Gas (Boiler)	£7,183.2	-------	-------
Cost of Gas (CHP)	----------	£9,233.04	-------
Total	£56,239.20	£48,653.04	£7,586.16

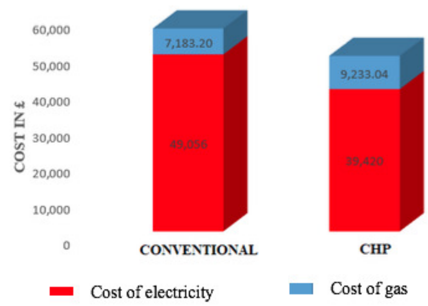

Fig. 1 Cost of fuel for conventional and CHP system at the hospital

Fromfig1 andtable 1, it canbeseenthat installing CHP at Christie unit in Stanford Royal NHS Foundation savesthehospital £7,586.16 per year. It canbededucedthat, the cost of electricitywasreducedby 19.6% whiles the cost of gas hasbeenincreasedby28.5%. Overall,the cost of electricityandheatwillbereducedby 15.59% when CHP isinstalled. The case studyhasrevealedthateffectiveandefficient installing of CHP reducesthe cost of electricityandheat of a building.

6. CONCLUSION

The use of electricity for thermal generation has lowefficiency. The low efficiency has resulted in large release of harmful substances into the environment that makes it unsafe for human lives. There is, therefore, the need to employ CHP to harness waste heat to increase efficiency in the usage of primary fuel. This paper has explained the applications and selection of CHP to fit a specific use. Understanding buildings thermal, electricity requirements, its operating conditions and period are essential in deciding on the installation of CHP. In addition, there is the need to estimate the cost of savings and financial returns on the installation of CHP before it is employed. Moreover, the environmental and economic benefits of CHP is well outlined; reduction of CO_2, nitrogen and Sulphur diode and reduction of energy cost. In conclusion, the effective and efficient application of

CHP in a building may address some environmental challenges in the world andas well save cost.

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