

# *CHP Microturbine Configuration Model and Economic Analysis*

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## ABSTRACT

Energy produced at the power plant has losses until it reaches the end-use site. Approximately two thirds of source energy is lost on the way. These are thermal losses at the power plant and losses in transmission and distribution systems. Energy prices are constantly rising. Energy security is another major issue for industry. All these aspects force industries to produce their own energy onsite.

The use of mainframe gas turbines for power generation has increased in recent years and is likely to continue to increase. The proportion of power generation using combined heat and power is also growing mainly because of efficiency improvements and environmental benefits. Mini- and microturbines offer a number of potential advantages compared to other technologies for small-scale power generation, particularly for distributed power generation, although there are some technical and non-technical barriers to the implementation of the technology. Small turbines could be used for power generation in the industrial, commercial and residential sectors.

The best common use of source energy is the production of combined heat and power (CHP). To optimize return on investment, systems are sized to have maximum utilization and minimum idle time. A detailed study considering the electrical and thermal energy needs of a hotel building located in Istanbul was carried out. Thermal and electrical peak loads of the building were measured and recorded. The peak electricity demand of the building was found to be 694 kW. Domestic hot water (DHW) and heating loads are 487 kW. Seven micro turbines of 65 kW (nominal electric power) are required to meet all the thermal energy needs of the building. The electricity generated by the microturbines is to be used to reduce electricity demand of the building. The analysis

showed that 100% of thermal load and, 55% of electrical load is met with the selected capacity.

Investment and operational costs are taken into account in calculating the feasibility of the project. In this study the net present value method is used for detailed life cycle cost economic analysis.

## INTRODUCTION

Turkey has dynamic economic development and rapid population growth. It also has macro-economic and especially, monetary instability. The net effect of these factors is that Turkey's energy demand has grown rapidly almost every year and is expected to continue growing, but the investment necessary to cover the growing demand has not been forthcoming at the desired pace. Since 1990, energy consumption has increased at an annual average rate of 4.3% [Akpınar, et al 2008].

Total electrical energy produced in Turkey in 2007 amounted to 176 TWh, and installed capacity is 42,053 MW. The electricity was produced by the following systems: 80.3% by thermal power plants, which used natural gas, coal and oil as fuel; 19.5% by hydroelectric power plants and 0.2% by wind and geothermal energy. In the distribution of electricity to the consumers, about 22% of the energy was lost in the distribution lines [MENR 2007].

The main sources of energy in Istanbul to meet heating, domestic hot water (DHW) and cooking are natural gas and oil. Summarizing, 73.2% of the electricity production, and 100% of the thermal energy requirements of buildings (for heating, domestic hot water and cooking) are met by employing fossil fuels, particularly natural gas (NG).

Turkey has small proven natural gas reserves. Natural gas consumption began in 1987 and has increased rapidly, particularly since

**Table 1. NG consumed by sector in Turkey (2006)**

<i>Sector</i>	<i>Natural Gas Consumption (<math>10^9 m^3</math>)</i>	<i>%</i>
Power	13.226	59.8
Fertilizer	0.527	2.4
Industry	3.891	17.6
Residential	4.462	20.2
Total	22.108	

the mid 1990s (see Figure 1). Turkey's indigenous gas production corresponds to 3-6% of the total gas demand. Therefore, the country almost fully depends on imported gas. Turkey's primary energy reserves are not enough to meet energy demand. Turkey is an energy-importing country, which imports more than 74% of total energy consumption, see Figure 2 [MENR 2007]. With advances made in recent years in the design, manufacture and operation of micro gas turbines, these units seem to be excellent candidates for on-site production of electricity, and the reduction of fossil fuel consumption for the thermal energy needs of buildings.

On the other hand, it is impossible to evaluate energy sources independent from their influence on the environment.  $\text{CO}_2$ ,  $\text{SO}_2$  and  $\text{NO}_x$  emissions from fossil fuel combustion play an important role in atmospheric pollution. The emissions of hazardous air pollutants from coal combustion have become an important issue in light of the new environmental regulations in several developed countries and these pollutants have been the subject of important research activities in recent decades [Yan, et al 2002]. Global warming is considered a potentially serious environmental problem and the use of fossil fuels for electricity production is one of its main causes [IPCC 2001].

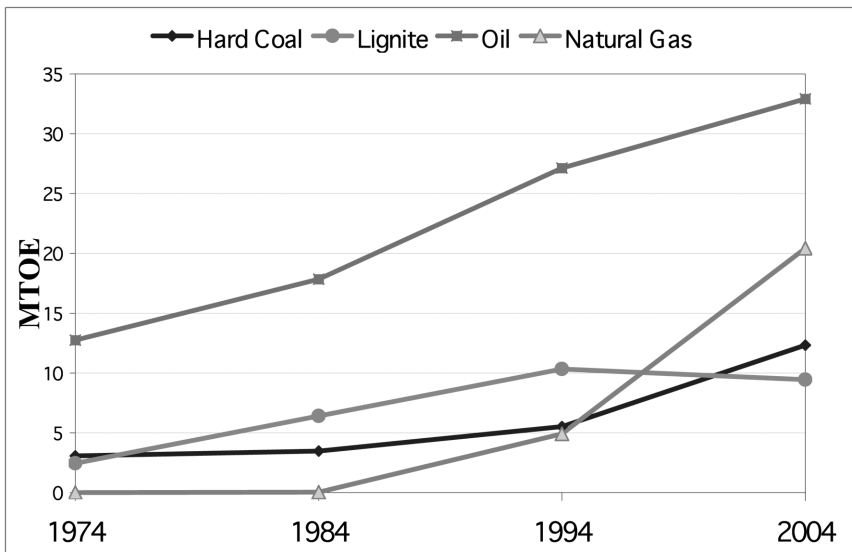


Figure 1. Energy demand of Turkey during 1974-2004

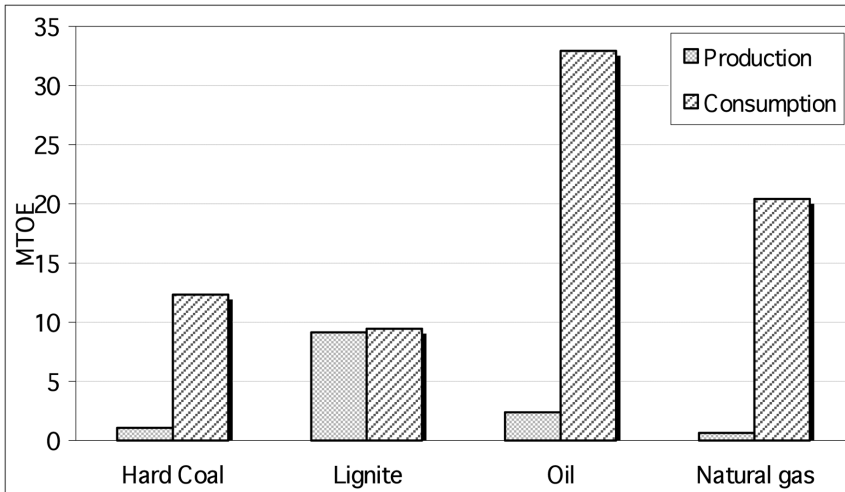


Figure 2. Primary energy production and consumption of Turkey (2006)

Table 2. Energy density of some countries

Country	Energy Density (MTOE/Million \$)
Japan	0.09
USA	0.25
OECD	0.19
World	0.29
Turkey	0.38

## CHP TECHNOLOGIES

Cogeneration, or combined heat and power (CHP) technology, is the combined production of electrical power and useful heat. In electricity generation from fossil fuels, the waste heat can be recovered from the cooling water and combustion gases to be used for heating purposes such as space heating, heating domestic water and driving absorption chillers for cooling applications. Cogeneration technologies for residential, commercial and institutional applications can be classified according to their prime mover and from where their energy source is derived.

Cogeneration systems and equipment suitable for residential and small-scale commercial applications like hospitals, hotels or institutional buildings are available, and many new systems are under development. These products are used or intended for meeting a building's electrical and thermal demands for space heating, DHW heating and potentially, absorption cooling.

There is a growing potential in the use of micro-cogeneration systems in the residential sector because they have the ability to produce both useful thermal energy and electricity from a single source of fuel such as oil or natural gas with high efficiency. In cogeneration systems, the efficiency of energy conversion can increase to over 80% compared to an average of 30–35% in conventional fossil fuel fired electricity generation systems [Onovwiona and Ugursal 2006].

#### ESTIMATION OF THE ELECTRICAL AND THERMAL ENERGY NEEDS OF THE BUILDING

The hourly and monthly electrical, heating and DHW energy needs of the building under consideration were measured, see Figure 3. Loads obtained from daily tests and from utility bills were nearly identical. As can be seen from Figure 3, the maximum electrical power demand is 730 kW and occurs in August. Maximum LNG (liquid natural gas) demand is 487 kW and occurs in January. Average daily temperatures are shown in Figure 4.

#### MICROTURBINE CONFIGURATION

The thermal load of a building is considered in selecting the capacity of the microturbines. The number of microturbines is selected in such a way as to cover 100% of the building's thermal demand. The thermal capacity of the system is 15% more than peak thermal load.

The electrical and thermal capacity of the micro turbine under consideration is 65 kW<sub>e</sub> and 70 kW<sub>th</sub>, respectively. The electrical and thermal efficiencies are 29% and 31%, respectively. Seven turbines will meet the entire thermal load and 55% of the electrical consumption of the building. Figure 5 illustrates the electricity consumption before and after the microturbine application.

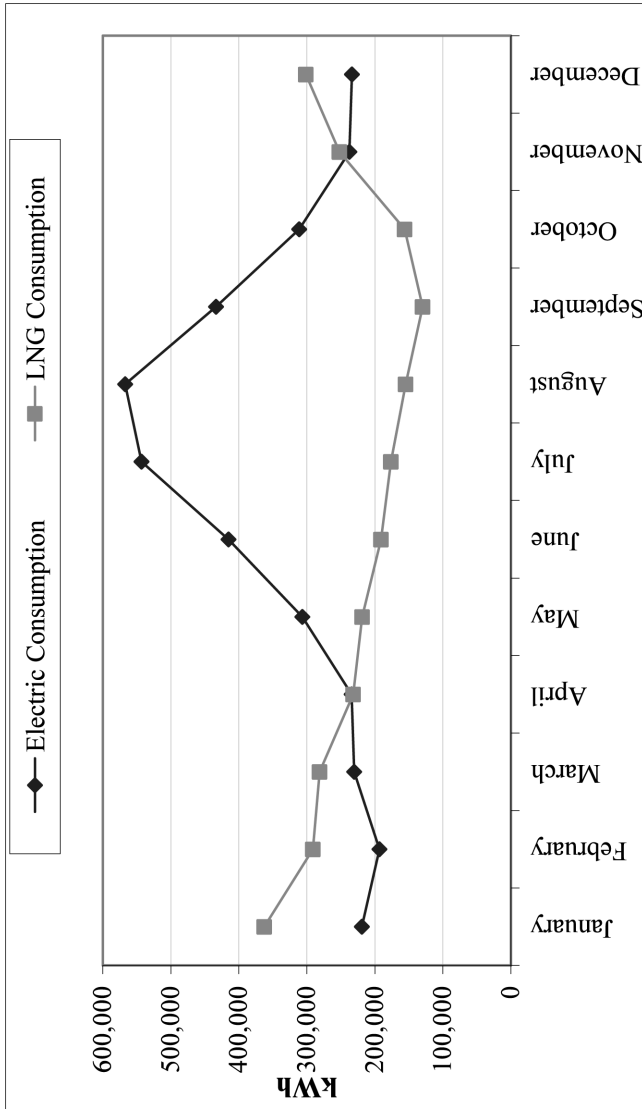


Figure 3. Monthly electricity and LNG consumptions of the building.

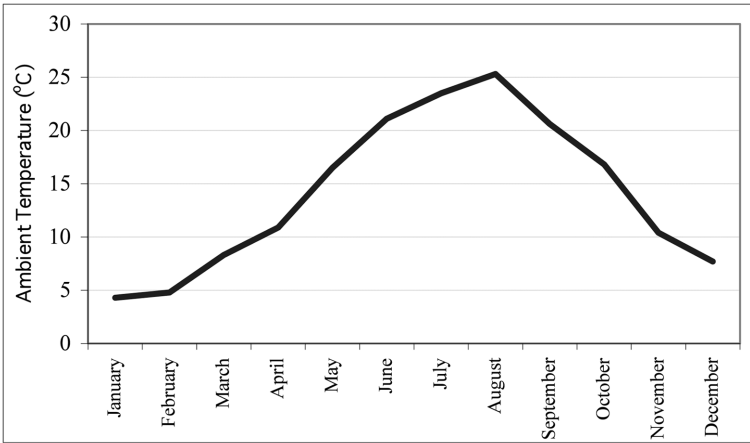


Figure 4. Daily ambient air temperature for 2007

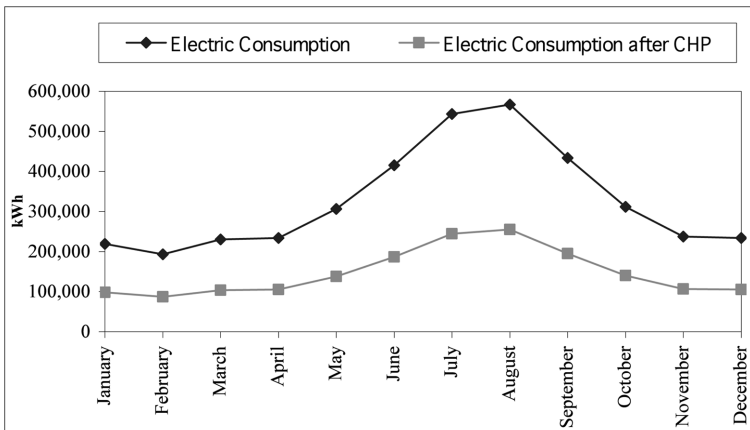


Figure 5. Electric consumption before and after gas microturbine application

### EMISSIONS OF HAZARDOUS AIR POLLUTANTS

When evaluating energy sources we should also consider the environmental impact. CO<sub>2</sub>, SO<sub>x</sub> and NO<sub>x</sub> emissions from fossil fuel combustion play an important role on atmospheric pollution. The emissions of hazardous air pollutants from coal combustion have become an important issue in light of the new environmental regulations in several developed countries. These pollutants have been the subject of important

research activities in recent decades [Yan, et al 2002]. Global warming is considered a potentially serious environmental problem and the use of fossil fuels for electricity production is one of its main causes [IPCC 2001].

The most important coal reserve of Turkey is the lignites. Unfortunately their low quality results in high environmental pollution with high sulfur and ash content. Turkish coal reserves constitute 0.88% of the European reserves and 0.11% of the total world reserves. Analyses show that the ash, moisture and sulfur content of domestic lignites vary a lot [Akçura and Gerger 1982; Arikol, et al 1984]. The share of the lignites containing less than 2% sulphur among the reserve is only 3.73%. Therefore nearly 96% of the lignites have high sulfur content. Lignites with less than 20% moisture content constitute 15.14% of the total reserves. Moreover approximately 69% of the lignites have calorific values under 8400 kJ/kg.

Compared to the conventional methods of generating heat and electricity separately, the use of micro-cogeneration systems can result in reduction of greenhouse gas emissions.

Greenhouse gas emissions arising from CHP also have been analyzed in this study. Table 3 shows the amount of greenhouse gas emissions from 1 kWh of electricity production at the power plant and burning of 0.097 m<sup>3</sup> (1 kWh) of natural gas.

**Table 3. Emissions produced per kWh of source energy by generating 1 kWh<sub>el</sub> at utility power plants and by burning 0.097 m<sup>3</sup> (1 kWh) of natural gas in Turkey [TEAS 2008]**

<i>Emission</i>	<i>Electric</i>	<i>Natural Gas</i>
CO <sub>2</sub>	0.515 kg/kWh	0.183 kg/kWh
NO <sub>x</sub>	1.267 g/kWh	0.342 g/kWh
SO <sub>x</sub>	2.999 g/kWh	0.004 g/kWh

The electricity and natural gas consumption of buildings for the existing situation and after CHP application is given in Table 4.

As can be seen in the graph, the natural gas consumption has increased whereas grid electricity consumption has decreased. In calculating emissions occurred by electricity consumption, the fuel burned at the power plant is considered to have 33% overall electric grid efficiency.

**Table 4. Building electric and natural gas consumption**

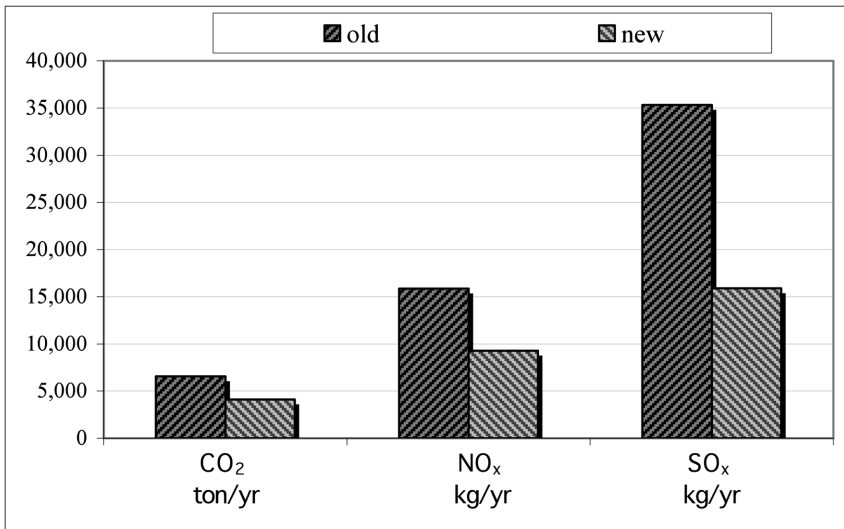
	<i>Electric (kWh/yr)</i>	<i>Natural Gas (kWh/yr)</i>
Old System	3,926,001	2,740,718
New System	1,762,791	7,514,873

There will be 2,468 T/yr of CO<sub>2</sub>, 6.6 T/yr of NO<sub>x</sub>, and 19.5 T/yr of SO<sub>x</sub> emissions reductions after the calculations. These reductions are shown at Figure 6.

### ECONOMIC ANALYSIS

To investigate project feasibility, this study takes into account investment costs and operational costs. Net present value, simple payback period and internal rate of return are calculated by detailed economic analysis. Assumptions include an analysis period of 20 years, a discount rate of 5%, and the residual value of 10% of the installed cost.

To start the analysis, electricity and LNG consumptions are determined. The thermal load is found to be 487 kW<sub>th</sub>. The boiler capacity



**Figure 6. Emissions for old and new conditions**

is calculated by increasing this number by 15%, yielding 560 kW<sub>th</sub>. To cover the entire thermal load, 7 microturbines, producing 490 kW<sub>th</sub> are required. Feasibility is calculated based on this number. Analysis showed that the microturbines can cover 55% of the electricity needs. In calculating the investment, unit cost of microturbines, transportation, site preparation, installation cost and waste heat recovery boiler costs are taken into account. Operation and maintenance cost are accounted for in the operating costs.

Based on the information from the vendor's technical specifications the re-investment period for microturbine is 40,000 hours of operation. This indicates that microturbines have to be overhauled in the 9th and 17th years. Table 5 summarizes the results of the economic analysis calculations.

**Table 5. Investment summary**

<i>Fiscal Savings</i> (\$/yr)	<i>Net Investment</i> (\$)	<i>NPV</i> (\$)	<i>Life-Cycle Cost Indicators</i>	
			<i>Internal Rate of Return</i>	<i>Simple Payback</i>
\$68,000	\$579,000	\$61,000	6.3%	8.5 yr

## CONCLUSIONS

In this study, the capacity of the microturbines is selected to cover the entire DHW and space heating needs and 55% of the electricity needs. The feasibility study showed that the simple payback period is 8.5 years, internal rate of return is 6.35% and net present value (NPV) is \$61,230. Because the NPV is so positive, we can conclude that this is an applicable project. On the other hand, the microturbine will cause 2,468 T/yr of CO<sub>2</sub>, 6.6 T/yr of NO<sub>x</sub>, and 19.5 T/yr of SO<sub>x</sub> reduction.

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#### ABOUT THE AUTHORS

**Mr. Sezgin Şah** graduated in 2005 with a Bachelor's degree in mechanical engineering from Osmangazi University in Eskisehir, Turkey. Currently, he is working toward an MSME at Yildiz Technical University in Istanbul, Turkey. Since 2006, he has been working as an energy engineer in Turkey's first ESCO (Envo Energy Services, formerly GlobalNet Energy Services). Sezgin's experience includes energy audits and energy projects in the hotel sector, a steel fabrication plant, the tobacco industry, the retail industry (both food and non-food) a pharmaceutical production plant, the cement industry, a chlorine-alkali caustic soda plant, a container port, automotive parts manufacturers, the textile industry, beverage can production, a paper mill and a paper packaging plant. Sezgin is working to establish the first AEE chapter in Turkey. Mr. Sezgin Şah may be contacted at [sezginsah@gmail.com](mailto:sezginsah@gmail.com).

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