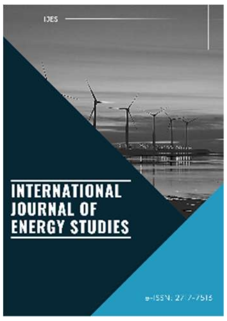
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2023; 8(3): 401-421

DOI: 10.58559/ijes.1326395

Received : 12 July 2023
Revised : 30 July 2023
Accepted : 04 Aug 2023

Analysis of electricity generation with combined power systems for residential buildings

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Highlights

- The combined use of solar, wind and cogeneration systems for residential buildings was simulated.
- SketchUP software was used in the simulation process.
- The advantages and disadvantages of the combined system utilization were investigated.

You can cite this article as: Aküzüm E, Çiftçi E. Analysis of electricity generation with combined power systems for residential buildings. Int J Energy Studies 2023; 8(3): 401-421.

ABSTRACT

Today, energy needs are increasing rapidly. Since our country imports a large part of its energy resources, it is extremely important to use energy efficiently and protect the environment in order to leave a livable world to future generations. One of the losses in energy transmission is transmission loss. In order to prevent this loss all over the world, "distributed energy production" method should be encouraged. Through combined heat and power systems, we can generate heat and electricity and save energy. Cogeneration systems can generally pay for themselves within 1.5-4 years. The aim of this study is to contribute to science with a broad literature review including the design of combined power systems and the technical and economic evaluation of their most efficient applications. The systems in the literature are investigated and comparisons are made. Hydrogen fuel cell types for domestic applications are detailed and hydrogen is considered to be a logical choice. The effects of design and performance parameters are analysed. This combined power system does not harm the nature; it utilises natural resources such as wind, sun and hydrogen, which can also be obtained by electrolysis of water.

Keywords: Combined heat and power systems, Cogeneration, Solar energy, Sketchup

1. INTRODUCTION

With the increasing population in the world, our energy consumption is gradually increasing. The developing technology also enables energy to enter our lives more and more, and energy is indispensable. We know how even a small power outage of a few hours brings our lives to a standstill. Because fossil resources are limited, the need for energy is increasing day by day and important environmental problems have emerged while carrying out activities for industrialization, the whole world has turned away from fossil fuels that pollute the environment and to make the highest possible use of primary natural resources that are less costly in the long term. All over the world, investments and projects to increase the share of renewable energy systems in energy production and to increase nuclear energy facilities have gained importance.

The fact that enterprises need electricity and heat energy at the same time, especially since the electrical energy obtained as a result of mechanical energy conversion contains a significant amount of heat energy due to friction and high temperature of waste gases, has revealed the alternative of meeting heat and mechanical energy needs in the same facility. In this way, businesses can both increase energy efficiency and use resources more effectively. Cogeneration, known as combined heat and power generation, has become more important over the years with increasing economic and ecological sensitivity. There are many studies on combined cycle power plants in the literature. Karaagac et al. analysed a combined natural gas cycle power plant They stated that as an increment in ambient temperature, there was a 20% decline in specific fuel consumption in the direction of the decrease in air flow entering to the compressor and concluded that the environmental temperature has directly proportional to performance of the combined cycle power plant [1]. Karanfil et al. studied different types of cogeneration systems including fuel cell-based and concluded that cogeneration systems are better in terms of both environment and efficiency [2]. Yıldız and Ünver investigated the definition of micro-cogeneration and the types and comparisons of micro-cogeneration through the literature. Hydrogen fuel cell types for domestic applications were prsented in detail and gave information about the criteria for domestic fuel cell type selection. As a result, the applicability of the micro CHP system is defended in this study [3].

Here we will design and analyze the most efficient combined power system. The use of natural gas and renewable energy sources as primary energy sources in our country is gradually increasing. Due to its advantages such as high efficiency and commissioning in a very short time, natural gas fuel cell combined cycle power plants have been increasingly used in our country as electric power generation and combined power systems in recent years. Natural gas-fuelled combined cycle power plants have been increasingly used in the production of electrical energy in our country in recent years. Natural gas-fired combined cycle thermal power plants can be commissioned in a shorter time with lower installation costs compared to nuclear, thermal, and hydroelectric power plants using other fossil fuels. Steam turbines and gas turbines are used together in combined-cycle power plants. Gas turbines operating on natural gas are used to generate electricity, while the waste heat obtained from the high temperature of the exhaust gases is transferred to the boilers to produce steam, which is then used to generate electricity through steam turbines. In this way, energy efficiency is increased by combining gas turbines and steam turbines.

In combined cycle power plants, by combining the advantages of the high temperature of gas turbine cycles and the low bottom temperature of steam turbine cycles, a combined cycle efficiency of around 50% - 60% can be achieved to operate under design conditions. In this way, higher efficiency in energy production is achieved and more efficient utilization of resources is possible. In the improvement of existing power plants and the design of new ones, not only the conversion but also the utilization of energy should be investigated. In various studies, it has been observed that the calculation of exergy and energy efficiency is a useful method for energy utilization analyses [4-6].

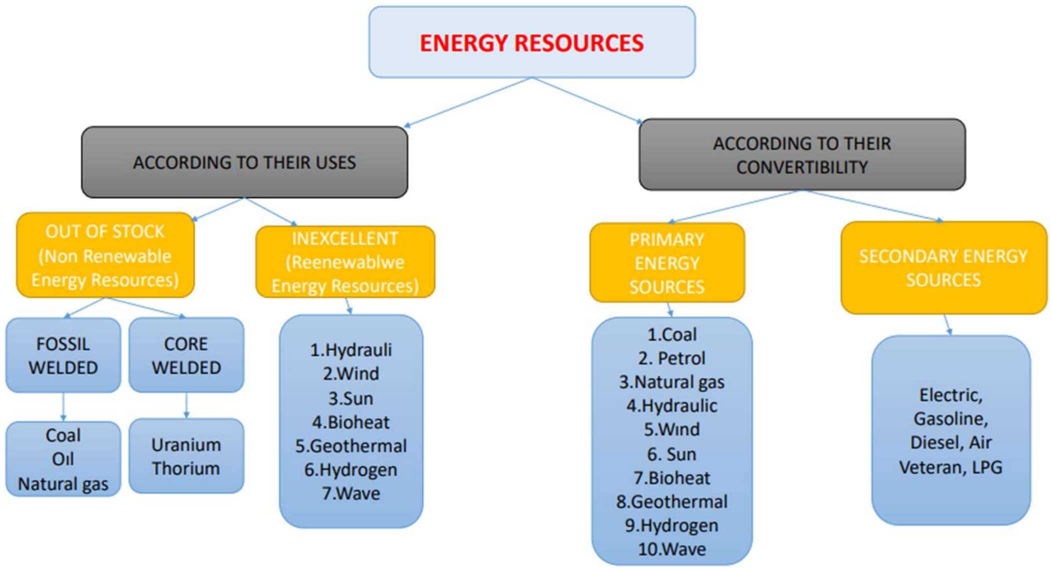


Figure 1. Grouping of energy resources

When we look at energy from a social and economic point of view, it is a very important factor that provides progress in living standards and development of countries in the world. The great developments in the fields of industry and the increase in the world population reveal the need for energy. While energy, which is involved in every aspect of life, was obtained by using fossil resources (oil, coal, etc.) in the past, today it is produced and consumed from renewable and convertible (solar, hydraulic, wind, etc.) energy resources [7, 8].

According to the information given in Figure 1, energy resources can be grouped under two different characteristics according to their usage areas and according to their convertibility. According to their usage, they are divided into parameters as non-renewable (exhaustible) and renewable (inexhaustible) energy sources, while they are grouped as primary and secondary according to their convertibility characteristics. The type of energy that has not been intervened in any way from the outside and has not undergone any change is called the “Primary energy source”. The sources are primarily; coal, sun, wind, natural gas, petrol, hydraulic, biomass, nuclear, and wave. The transformation of primary energy sources into different energy sources as a result of any external intervention is called a “Secondary energy source”. Exhaustible energy resources are energy resources that have a certain reserve and are expected to be exhausted in the future. These are under the heading of fossil resources, divided into groups such as coal, natural gas, and oil. Energy resources under the heading of inexhaustible are defined as renewable energy that can be obtained by natural means that are open to infinite use. The main ones are classified as hydraulic, hydrogen, wind, solar, geothermal, biomass, and wave. In particular, since renewable energy sources are obtained by natural means, there is no need for purchase from foreign countries or special production. And one of the most important features of renewable energy is that it does not harm nature´s carbon When we look at the types of energy consumed worldwide, we can say that renewable energy sources have great potential. However, oil is still in the lead, followed by coal and natural gas.

Energy Consumption Rates Since it also has the potential to reduce emissions, investment in these energy sources is increasing day by day worldwide [7-9]. The share of renewable energy in total primary energy consumption is only 9.5% (hydroelectric and renewable combined).

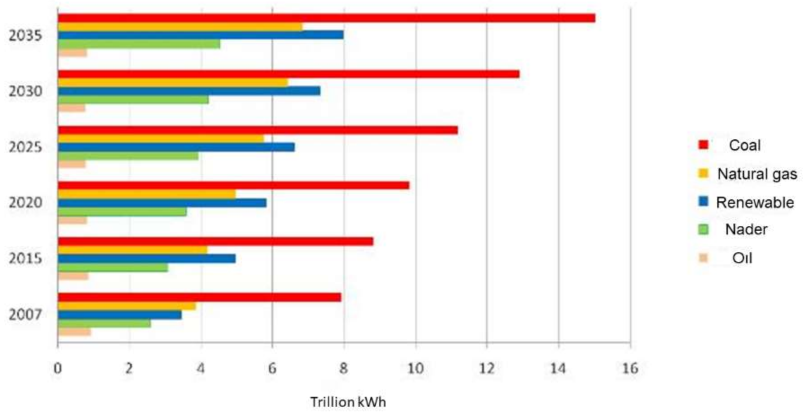


Figure 2. Share of energy sources in world electricity generation

As can be seen in Figure 2 above, increases in energy consumption are observed. In 2035, general energy consumption will reach approximately 16 billion tonnes of oil equivalent (TOE), which shows that the increase in the use of renewable energy sources will be higher than oil and nuclear energy sources after coal. When the shares of energy sources in electricity generation are analyzed and the information in the literature is reviewed, it can be seen that by using renewable energy sources and natural gas combined systems together, a brand new combined power system with almost no harm to nature and highly efficient in terms of efficiency can be obtained.

Progress in the field of energy shows the development of that country. In our current period, energy has become the most important factor in determining the quality of life of human life. The fact that energy has gained so much importance today shows us that we should utilize even waste energy and use it in transformations. Various studies are carried out in the literature on these issues. The continuous decrease in fossil resources in the production of electrical energy and the high level of environmental pollution make it necessary to turn to alternative sources [10].

Renewable, natural energy sources are the most important and endless alternative energy sources compared to fossil resources. With the advancing technology, renewable energy sources have become much more efficient sources and their usage area has also increased. Wind and solar energy stand out as the paramount forms of renewable energy. Studies on energy systems have gained importance both in non-academic platforms and in scientific circles due to various strategic determinations in countries and the necessity to transform them in a way that can respond to rapid changes in the world.

In the Energy Efficiency Law No. 5627, energy efficiency is defined as follows: It is aimed to use energy effectively, prevent waste, reduce the burden of energy costs on the economy, and protect the environment by increasing efficiency in the production, transmission, and utilization stages of energy resources [11]. Cogeneration systems meet the objectives of the energy efficiency law by producing heat and electricity or mechanical energy simultaneously in the same facility [12].

Basically, in a power cycle, both electricity and heat energy are produced by utilizing the heat discharged into the environment. Such cycles reduce fuel emissions and consumption compared to conventional cycles [13]. Energy should be produced where it is consumed, which increases efficiency and reduces transmission and distribution investments and energy losses. Uninterrupted and quality energy is provided. Cogeneration facilities are very important in terms of efficient use of energy, reducing energy costs, and protecting the environment. The energy produced in these facilities is low carbon [14]. Different from other studies, a new combined power system was designed and evaluated both technically and economically.

2. WORKING PRINCIPLE OF FUEL CELLS AND EQUIPMENT

A fuel cell is a chemical battery that converts chemical energy into electrical energy by combining hydrogen and oxygen in an electrochemical reaction. Each unit of the fuel cell consisting of anode, cathode, and electrolyte between these two electrodes is also called membrane electrode assembly (MEA). Each fuel cell produces less than 1 volt of electricity and hundreds of fuel cells must be connected in series to obtain high voltage. These series are called "fuel cell units". Fuel cells also use catalysts to increase the reaction rate [15].

3 main parts make a fuel cell work;

1. Hydrogen Reformer: It is the fuel stage that separates and extracts hydrogen from the fuel source (natural gas, propane).
2. Fuel Cell Arrays: Electrolyte materials are located between mutually charged electrodes. The hydrogen energy in the fuel is converted into direct current (DC) electrical power by electro/chemical reaction at this stage.
3. Inverter (Inverter): It is the stage that converts direct current (DC) to alternating current (AC).

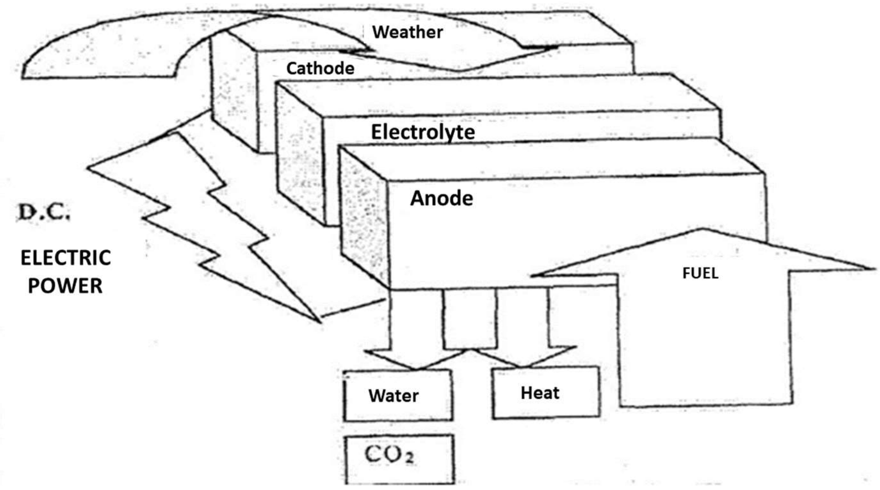


Figure 3. Schematic representation of the fuel cell

We prefer hydrogen fuel cells in combined heat and power systems because of their environmental friendliness and abundant availability in nature. The main fuel cell types currently under investigation are as follows [16]:

1. Proton exchange membrane fuel cell (PEMFC)
2. Alkaline fuel cell (AFC)
3. Phosphoric acid fuel cell (PAFC)
4. Molten carbonate fuel cell (MCFC)
5. Solid oxide fuel cell (SOFC)
6. Direct methanol fuel cell (DMFC)

PAFC is the most advanced type of commercial fuel cell. It is used in a variety of applications such as hospitals, hotels, government offices, schools, grid power stations, and airport terminals. The PAFC achieves 30% efficiency compared to internal combustion engines and up to about 85% efficiency when used with waste heat cogeneration. Without cogeneration, it can generate electricity with an efficiency of 40% and above. The operating temperature is 200°C [17].

3. WHY HYDROGEN?

In the production of hydrogen energy, no waste other than water is produced, it is an environmentally friendly fuel. It does not create greenhouse gas and carbon emissions. Hydrogen does not harm the environment during transport, storage, or use until it reaches the combustion stage. Hydrogen is an element found in very large amounts in nature. It is not in danger of depletion like fossil fuels. Renewable energy sources such as wind and sun can be used in the production of hydrogen energy. Hydrogen can be produced from natural sources. There is also hydrogen element in water. Hydrogen has the highest energy content per unit mass among all known fuels and is 1.33 times more efficient than petroleum fuels. Hydrogen, which is used very safely in industrial plants, power plants, and residences, is also an ideal alternative for motor vehicles with its high efficiency and low emission.[18]

4. ELECTRICITY GENERATION WITH COMBINED POWER SYSTEMS

CHP (combined heat and power) systems, also called cogeneration systems, are becoming more advantageous and usable for energy production today. In conventional power plants, heat is generated as a by-product of electricity and released into the environment. CHP systems possess the capacity to effectively harness and convert waste thermal energy into additional electrical energy or utilize it for alternative heating objectives. CHP systems have an average efficiency of 85 percent, much higher than conventional power plants.

CHP systems are of interest for industrial and commercial on-site electricity generation systems as well as rural distributed generation systems. CHP systems have the potential to supply sufficient thermal energy, thereby reducing the reliance on air conditioning systems in industrial and commercial buildings, while simultaneously fulfilling the electricity requirements of residential homes. In rural areas, the extracted heat can also be used for hot water supply in households. The 2 types of energy from a single system can provide significant energy savings compared to the individual electrical and thermal power generation processes. The benefits of CHP systems are given in the following order:

- Reduced emission of pollutants in the air (SO2, NO, and Hg)
- On-site power generation reduces dependence on the grid.
- Power can be supplied without being affected by power outages in the grid.
- In the case of an existing infrastructure, constraints can be overcome.
- Improved security, reduced energy cost, reduced initial installation cost, and increased resilience to power outages.

Fuel cells (Fuell Cells (FC)) are an ideal element for CHP systems in both large stationary power plants and distributed generators. In FC-based large stationary power plants, CHP systems are already in use, as high-power FCs operate at very high temperatures (800°C-1000°C) and without CHP the efficiency would be greatly reduced. On the contrary, distributed generators use low-temperature FCs (60°C-100°C) and CHP systems have recently been used in demand networks.

Several literatures have proposed FC-based CHP systems and show that the use of CHP systems helps to greatly increase efficiency [19].

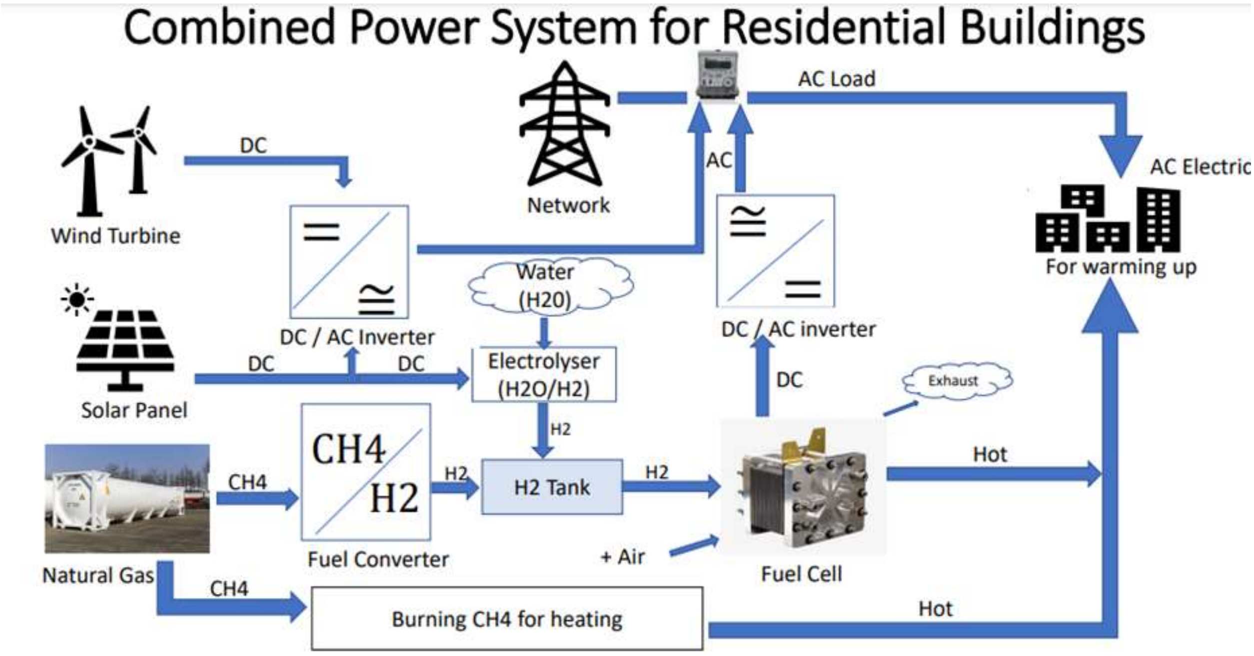


Figure 4. Combined power system for residential buildings

5. MATERIAL & METHOD

This study, in addition to actively using the heat and electrical energy of the cogeneration system in residences, it is aimed to produce energy continuously and with maximum efficiency by combining this whole system with solar and wind energy, so that we will use both solar, wind, and hydrogen with maximum efficiency, which will minimize the amortization period of the investment in the system. And the environmental impact of these systems is very low compared to the fossil resources currently used.

The working principle of the cogeneration system and the energy sources that can be obtained at the output are shown below.

Figure 5. Cogeneration system outputs

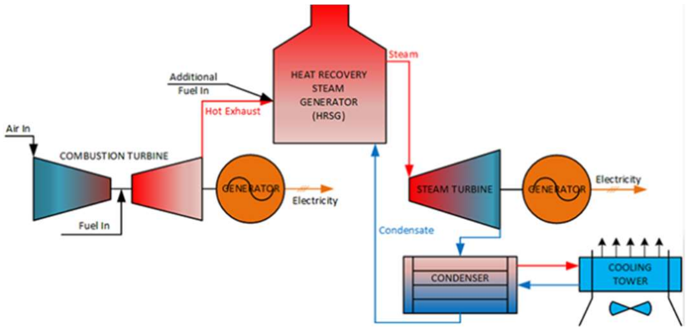


Figure 6. Combined cycle Cogeneration

The need for electrical energy is usually met by purchasing electricity from the electricity grid, while thermal energy is supplied by an on-site boiler or furnace. However, in a power plant, electricity generation is accompanied by heat generation. Disposal of this heat energy to the environment through the exhaust gases and cooling circuits of the power plant causes a great waste of energy. Most of this heat energy, referred to as waste, can be recovered and utilized to meet thermal loads [19].

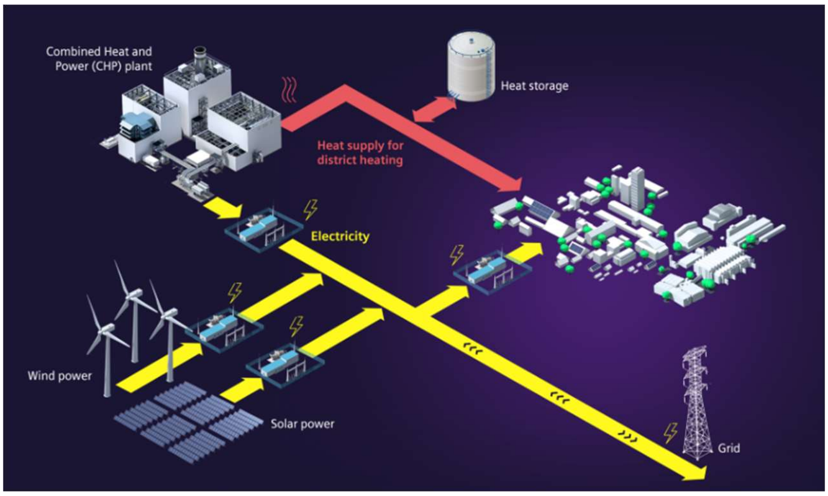


Figure 7. The working mechanism of the combined system [20]

Most equipment operates intermittently. However, equipment must be kept ready to safely meet the peak demand caused by this demand imbalance in public housing systems. More equipment and devices than necessary will increase the unit cost of electricity and heat. In such applications, a small gas turbine, boiler, and steam turbine can be produced safely and with low operating costs.

5.1. Thermodynamic Analysis of the Cogeneration System

In most engineering systems, the energy requirement is in the form of heat. Thermal processes have an important place in industries such as chemistry, paper, petroleum, steel, food, and textile. The heat required for thermal processes is called process heat.

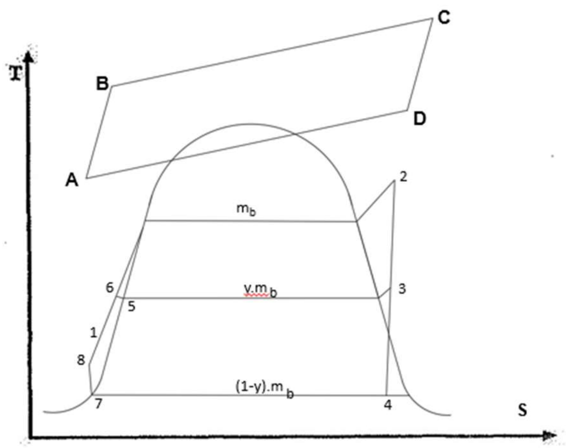


Figure 8. Combined gas steam turbine cycle

As shown in Figure 8, all state changes are considered reversible and calculations are made accordingly. In the gas turbine cycle, air (A) is compressed and pressurized by the compressor (B). The high-pressure air and fuel mixture burns in the combustion chamber at constant pressure and its temperature increases (C). Then the fluid expands isentropically from the gas turbine to point D. The high-temperature fluid leaving the gas turbine at point D comes at constant pressure in a waste heat boiler until E conditions, while the water entering the boiler at point 1 leaves the boiler as superheated steam at point 2. After point 2, all of the steam starts to expand isentropically and W(bt) work is obtained. At point 3, ymb of the steam is withdrawn for process heat and continues to expand until point 5. The remaining (1-y)mb of steam continues to expand isentropically up to the condenser pressure and some more work is obtained from the steam turbine (Wbt2). The ymb working fluid used for the process and the (1-y)mb condensed in the condenser are pumped into the mixing chamber by steam pumps and the cycle is completed (5,6,7,8).

5.2. Economic Analysis of the Cogeneration System

The initial investment cost of cogeneration systems varies significantly depending on the type of system and the desired capacity (Figure 9). Considering the same capacity value for a cogeneration plant to be installed with a steam turbine only or gas turbine only, the combined system is much more economical. This provides significant price advantages in the short and long term.

Depreciation refers to how much of the total investment cost value of the plant is recovered in one year. Calculations are made by considering that the plant will provide an equal amount of depreciation each year throughout the investment life. This method is called fixed annual depreciation or fixed annual capital cost. The fixed annual depreciation cost for an investment with a present value of I ($) is calculated as follows:

$$C_k = I\left[\frac{i(1+i)^n}{(1+i)^n-1}\right](\$/year) \quad (1)$$

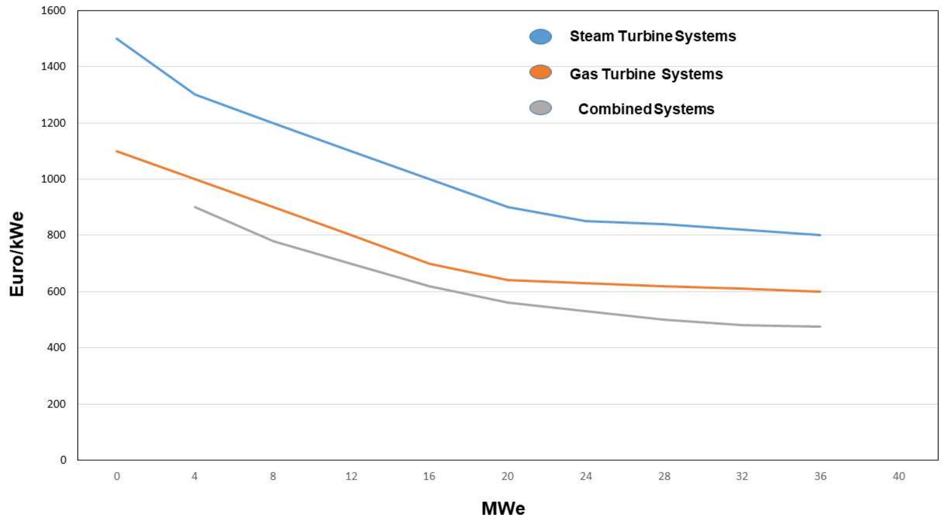


Figure 9. Cost of cogeneration systems

The multiplier [i(1+i)-]/[(1+i)n-1] in the formula is called "Investment Replacement Factor" or "Depreciation Coefficient". i is the annual interest rate and n is the period of use of the facility (years).

Operation and maintenance costs cover all expenditures such as labor, material supply, storage, repair and maintenance, insurance, etc. during operation. These expenses can be divided into two main groups:

- Annual fixed costs and costs that do not depend on the time of use or grid load factor,
- Annual costs varying in proportion to the energy produced.

6. THREE-DIMENSIONAL DESIGN AND SIMULATION OF THE SYSTEM

The design and analysis of combined systems is one of the important issues in the energy sector. Three-dimensional design programs such as Sketchup can be used as an important tool in this process. With this program, we can easily plan the layout of power generation and distribution lines and the placement of equipment. We can also create detailed models of systems such as combined cycles or combined cycles with SketchUp.

In addition, this combined power systems research, which was designed and calculated in 2D, was modeled in 3D and the locations of distribution lines, tanks, and fuel cells were determined, and any errors were observed in detail, redesigned, and corrected. By modeling this CHP system in three dimensions, it has become a more understandable and realistic project.

After the project was modeled in three dimensions, some nice improvements were made that could not be observed in two dimensions, the most important of which was to be able to place vertical solar panels on the building surfaces, another was to accurately simulate shading and sun angles, and to accurately determine and place panel and fuel cell locations. In the image below, a view from the back of the houses in the SketchUp design is attached. Inverters are placed on the wall just behind the houses to convert the DC from solar and wind energy into AC. The cells and tanks that are part of the cogeneration system are placed on the left side, away from the buildings.

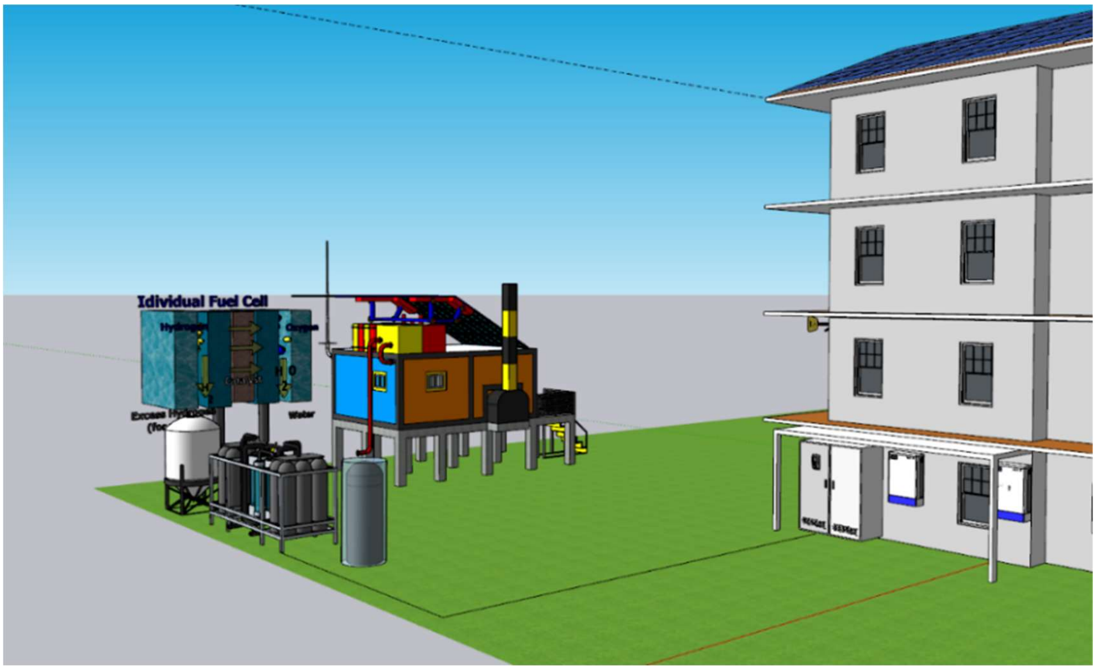
Figure 10. The SketchUp design of the designed system

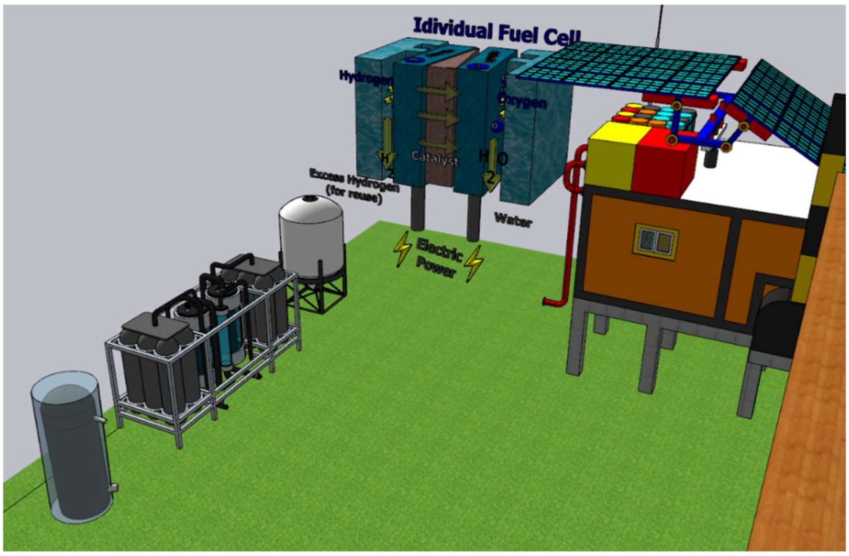
6.1. Main Parameters of the System

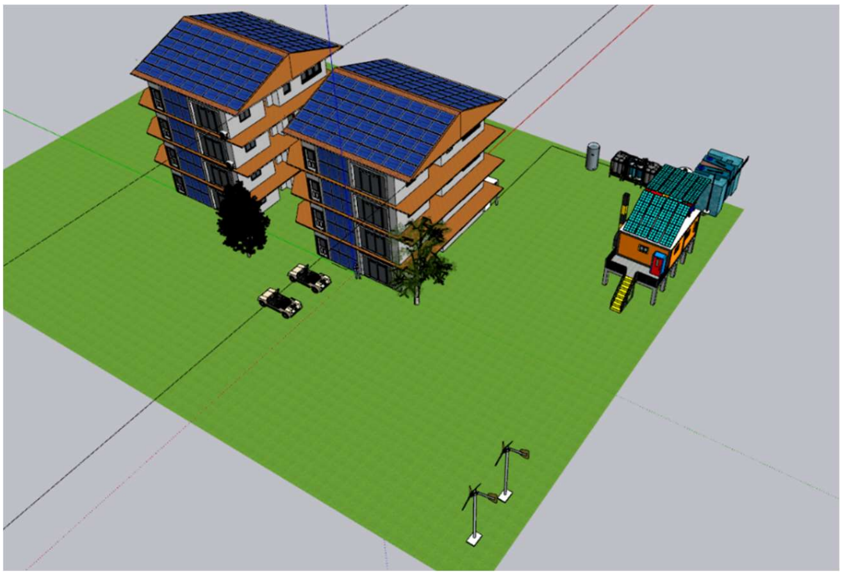
In this design, the dimensions of the buildings are designed as 20 meters by 13 meters. Special designs are made according to different structures. The main purpose of my combined power systems project was to use wind turbines, solar panels, and fuel cell systems together. To use it with maximum efficiency, the roofs of the buildings were designed with solar panels. In addition, with the simulations and experiences, it was thought that solar panels could also be placed on the outer side of the building, and when the efficiency was analyzed, it was observed how efficient it was both in terms of thermal insulation and energy production, and the panels were placed on the side surfaces of the buildings that received the most sun and were efficient. Later, wind turbines were also placed on the land where the buildings are located according to the characteristics of the land.

The fuel cell in this project is a hydrogen-burning cell and the hydrogen was obtained with an electrizer using water, which is very abundant in nature and has no harm to the environment and sent to the fuel cell. Again, a CH_4 tank is placed next to the system to make it complete, and if it is insufficient or if it encounters various problems, Hydrogen obtained from CH_4 methane gas can also be used in the same way. The fuel cell burns the hydrogen gas and outputs electrical energy and heat energy. DC power is converted to AC through inverters as we do in solar and wind turbines and sent to the grid through bidirectional meters. The resulting high-temperature liquid is first circulated on the land surface, preventing the roads from freezing in winter and cooling the liquid a little, which prevents the roads and garage entrances and exits from freezing, especially in winter. This heat can then be used for home heating in buildings.

The electrizer consumes electricity to produce hydrogen from water (H_2O) and this electricity can be supplied DC from the electricity generated by the solar panels. Next to the cell, there is a cell room for waste heat and electricity, located at some distance from the tanks and buildings, where the final processing is carried out before being sent to the grid. Again, solar panels are placed on top of this cell room to provide shade and generate energy. You can see different angles of this three-dimensional design below.


Idividual Fuel Cell
Water


Idividual Fuel Cell
Hydrogen
Oxygen
Catalyst
Excess Hydrogen (for reuse)
Water
Electric Power



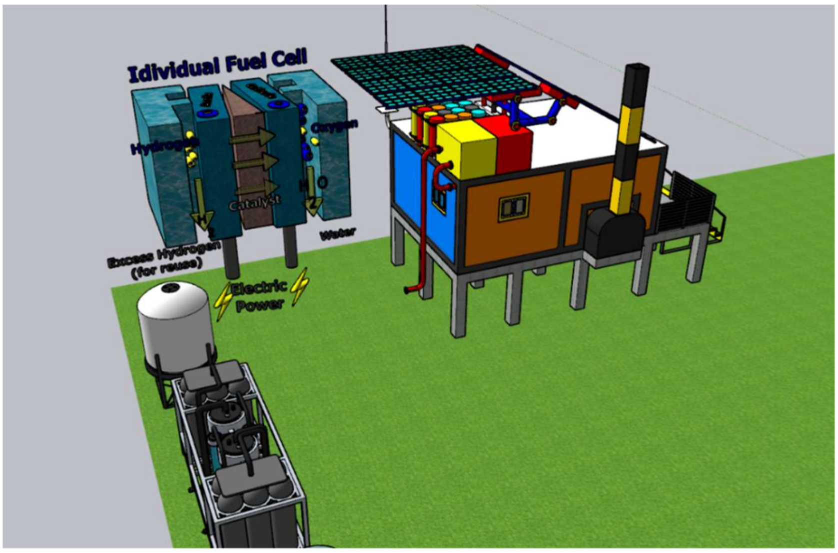


Figure 11. The designed system from different points of view

7. RESULT & DISCUSSION

As a result of all the analyses obtained, it can be observed how efficient this combined power system is. By placing solar panels on the side facades of the houses, gains are achieved in 3 different areas such as electricity generation, building insulation, and space-saving. In this way, while you can generate electricity during the day thanks to the sun, you can continue to produce uninterrupted energy with wind turbines at night thanks to the wind. At the same time, thanks to the fuel cell system, hydrogen is produced from water without harming the environment, and the hydrogen produced by the fuel cell can be burned to generate heat and electricity. As comparison, Karaagac et al. found that they operate only on natural gas and are efficient. However, natural gas is an exhaustible fossil fuel, its exhaustibility should be evaluated and long-term investments should be made accordingly. Through fuel cell systems, hydrogen, which is abundant in nature, can be used as fuel without harming the environment and thanks to its high efficiency [2]. The study of Karanfil et al. also supported this phenomenon [3].

The fuel cell does not harm the environment because only steam comes out of the exhaust. The very high-temperature liquid is circulated on the ground, cooled naturally, and finally designed to be used for heating houses with thermal stabilizers. In this way, it not only meets the need for heat without any cost but also prevents freezing in winter by heating the road, such as the garage entrance of the site.

In cogeneration, the process heat value decreases as the amount of steam separated decreases, but the work taken from the steam turbine increases in return. For low values of steam produced or withdrawn for the process, the system resembles a conventional stand-alone system that generates mechanical power and the energy of the exhaust gases is less utilized. As the power/heat ratio increases, there are expected decreases in the amount of heat gained. This result was also obtained by Karaagac et al. [1].

Micro cogeneration systems should be made widespread in our country to reduce transmission losses by producing energy where it will be used with distributed systems and to minimize greenhouse gas emissions by obtaining high efficiency in energy production. It is recommended that research on this subject should be increased and increased in our country. The results obtained in this study are as follows:

- In Europe, a target of 3000 € is set for the widespread use of domestic micro-CHP systems.
- For such systems to be widely used in our country, it is recommended that the price should be below the targeted figure for Europe and that it can be an alternative to the boiler and its production should be carried out in our country.
- To produce production and technology in our country, studies on micro-CHP systems should increase.

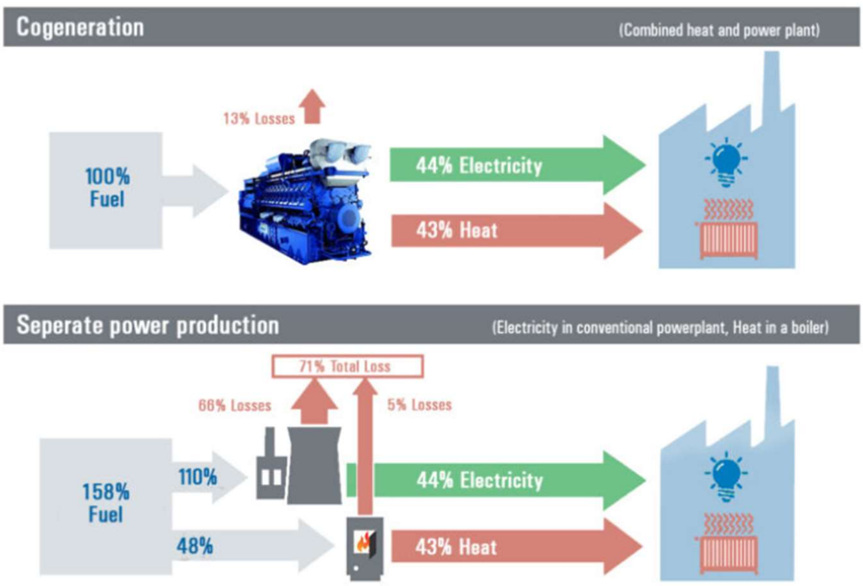


Figure 12. Cogeneration and trigeneration outputs

Cogeneration systems play an important role in meeting the increasing energy demand in parallel with population growth and technological development. Domestic cogeneration systems have been developed to meet the need for electricity and thermal energy from a single source. In this study, the characteristics, types, and comparisons of domestic cogeneration systems and their status in the world were examined. As a result of the research, some of the issues that should be considered economically and environmentally before choosing the installation of domestic cogeneration systems can be given as follows:

- From an economic point of view, installation cost, annual expenses, and payback period should be analyzed together with comparable environmental factors such as emission values and noise, which cannot be ignored.
- The advantages of internal combustion engine systems are the high electrical power that they can generate, low investment cost, and payback period, while the disadvantages are noise and high emission values.
- While fuel cell-based systems have the advantages of low emission values, low annual maintenance costs, and very quiet operation, the high initial investment cost and payback period are seen as the biggest obstacles to their commercialization.

As stated earlier, Figure 4 shows the design of a combined power system for residential buildings. In this design, the DC power from wind and solar energy is converted to AC with an inverter and sent to the grid. On the other hand, we produce energy with natural gas, natural gas is first converted into hydrogen with a fuel converter and sent to the fuel cell, at the same time, it is known that there is hydrogen in water, which is abundant in nature, these hydrogen molecules in water can be separated with the help of an electrolyzer and DC power for the electrolyzer to work can be provided from solar panels. The electrolyzer is a very low-cost system. Energy and heat are obtained by burning the hydrogen we obtain in the fuel cell together with air, which is also abundant in nature. The energy obtained is sent to the grid. The heat in the pocket water of the fuel cell is also planned to be used in homes for heating. A natural gas heating tank is also designed in the system to be a backup in heat production. With the bidirectional meter, a profit can be made by taking the amount of electrical energy used and selling the unused amount to the state. In this way, all the energy required for the houses can be provided without harming the environment. In compariosn, Yılmazoğlu et al. provided the reasons for the preference for engine, turbine, and fuel cell-based systems are given and stated that engine-based systems were preferable in terms of initial investment costs. However, the efficiency, environmental friendliness and longevity of fuel cell-based systems should be preferred considering that the sustainability of the system is an important parameter [21]. In the meantime, superheated steam, which is not harmful to the environment, comes out of the exhaust outlet of the fuel cell, and in future projects, electricity generation with a steam turbine can be considered from the steam coming out of this exhaust outlet.

8. CONCLUSION

As a result, fuel cell-based cogeneration systems can be preferred when a quieter, environmentally friendly (low emission values) system is desired. However, since these systems have not yet been widely produced and used, they are not economical. However, for 1-50 kW energy needs in domestic applications, cogeneration systems with internal combustion engines are widely preferred due to their advantages such as high generation power, more accessible and installable technology, and a short payback period.

According to calculations and analysis, these combined systems pay for themselves and generate profits within 4-5 years on average (depending on the size of the system and the change in electricity prices. This is a conclusion based on the above analysis).

As a result, with these combined systems designed, we can continue to produce the energy used without interruption, use every resource offered by the world with maximum efficiency and continue to produce endless energy without polluting the world. As can be seen in the Sketchup design, it does not pose any negativity in terms of environmental appearance. In addition, if it is not enough to use the energy produced free of charge, the energy produced can be sold to the state to generate extra income.

NOMENCLATURE

AC: Alternating Current

C: Annual costs

CHP: Combine Heat and Power

DC: Direct current

i: Interest rate

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Eren Aküzüm: Performed the simulation and analyse the results and wrote the article.

Erdem Çiftçi: Supervised, edited, and controlled the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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