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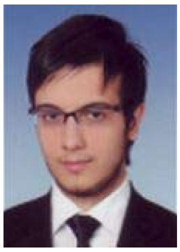
The performance assessment of fuel cell technology in residential application

The article describes the status of fuel cell technology for domestic applications nowadays according to the comparison methodology. Fuel Cell system integrated with conventional system and heat pump has been designed for a resident in four temperate zone of Turkey. This study shows us Fuel Cell system applicability changes in different climatic zones.

Keywords: fuel cell, fuel cell system, domestic fuel cell application, SOFC, PEMFC.



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The background of the Fuel Cell system needs

Domestic applications comprise a large portion of energy consumption. Engineers are looking for more efficient technologies for providing less consumption. So, fuel cell systems have become important to use in applications. Advantages and disadvantages of this system are discussed in many applications at the present time. The findings of the research reviewed for an explanation of the discussions. From past to present, investment cost of fuel cell systems has been the biggest difficulty. The main question has been "Developments in fuel cell technology sufficient to apply today?" yet.

Introduces Fuel Cell systems

Fuel cell systems have high efficiency conversion technologies with high conversion rate and there is no harmful environmental effects of fuel cell systems. Due to the increasing demand for small powers, fuel cell systems have been used for domestic applications as the power source. Therefore, fuel cell systems can be used as resources to help for long-term use of renewable energy sources. [1]

The best way for the fuel cell system design is using real data from an annual energy demand for residents. In general, the energy demands of residents can be categorized as electrically and thermally. [3]

There are two main parameters that determine the performance of a fuel cell system. Efficiency is the first and most important of them. The second parameter, decrease in system performance. [1]

Table 1. The general properties of a fuel cell unit can be used in residential applications.

Output (kWh)	Electricity	1
	Heat	1.3
Efficiency (%)	Electricity	34
	Heat	44
Source		Natural Gas
Size (mm)	Height	800
	Width	500
	Depth	580

The most easily available sources are natural gas for the fuel cell. Fuel cell using natural gas has lower efficiencies at partial loads. Initially, it requires pre-heating and cannot respond quickly to unstable demands. [2] **Table 1** shows the general properties of the domestic fuel cell unit.

Literature review

Several fuel cell systems have been proposed and analyzed in the literature. Both solid oxide (SOFC) and proton exchange membrane (PEMFC) fuel cells can be used for residential applications.

Krist and Gleason analyzed the feasibility of fuel cell cogeneration systems for residences [6]. The analysis suggests that fuel cell based cogeneration systems are suitable for residential applications. However, the analysis by Krist and Gleason only considered the load requirements of the residence in peak summer and winter days, and the analysis of the system is based on the performance in these conditions. Fuel cells are considered as a very good alternative to current technologies in many power generation applications.

Hirschenhofer [7] and Kordesch [8] describe the basics of PEMFC systems. The companies claim that their products will produce electricity competitive with current residential electricity rates and that they will introduce significant cost savings, especially at locations where electricity is more expensive and natural gas cheaper than the national average [9].

As a result, in future, if the provision of housing by the hydrogen distribution networks, widespread use of fuel cells will become houses. [2]

Comparison methodology

The method includes a fuel cell and a conventional energy supply system. Systems have been designed with the same reference residents in four climate zones. Benefits of fuel cell has been identified in each zone.

Four climatic zones exemplify different heating degree days (HDD) and cooling degree days (CDD). The first zone located in the warm climate. This zone has 983 HDD and 627 CDD, 130 days are below 15°C and 137 days are over 22°C per year. The second zone located in the moderate climate. Second zone has 1702 HDD and 169 CDD, 186 days are below 15°C and 88 days are over 22°C per year. The third zone is good example for cold climates. The zone has 2327 HDD and 165 CDD, 204 days are below 15°C and 68 days are over 22°C per year. The fourth zone is a terrestrial climate. This zone has 4665 HDD and 2 CDD, 286 days are below 15°C and 5 days are over 22°C per year.

The benefits of fuel cell are operating costs and carbon emission. Operating costs represent a reduction in natural gas use and also a sign that more efficient use of resources. Carbon emission represents environmental pollution.

Annual energy demand has been identified for the reference resident. Energy demand has been comprised of heating and cooling loads, hot water and electricity for appliances. Saving of operating costs and carbon emission have been calculated in annual and 15-year period. The net present value method has been used in long term calculations. Carbon emission values have been computed from international carbon footprint data. The simple payback period method has been used for calculating payback period.

The reference resident is double-decker, four persons live and the living area is 206 m² (**Figure 1**). Daily electricity demand value is 16 kWh and the average domestic hot water usage is 300 liters.

The conventional system comprises a condensing boiler for heating and domestic hot water, a chiller unit for cooling. In the reference resident, fan-coil units are used for heating and cooling. Electrical demands met by the city network.

The fuel cell system (**Figure 2**) comprises a heat pump for heating, domestic hot water, cooling and electricity. In the reference resident, fan-coil units are used for heating and cooling. The fuel cell unit provides electricity to the heat pump and the fuel cell unit to produce electricity from natural gas.

Carbon emission comprises the whole process of production. The whole process involves natural gas and electricity producing to use.

All these data have been used in Hourly Analysis Program to compute the heating and cooling loads. Hourly Analysis Program (HAP) is an energy simulation program from Carrier©. HAP is an internationally recognized and uses ASHRAE standards with databases.

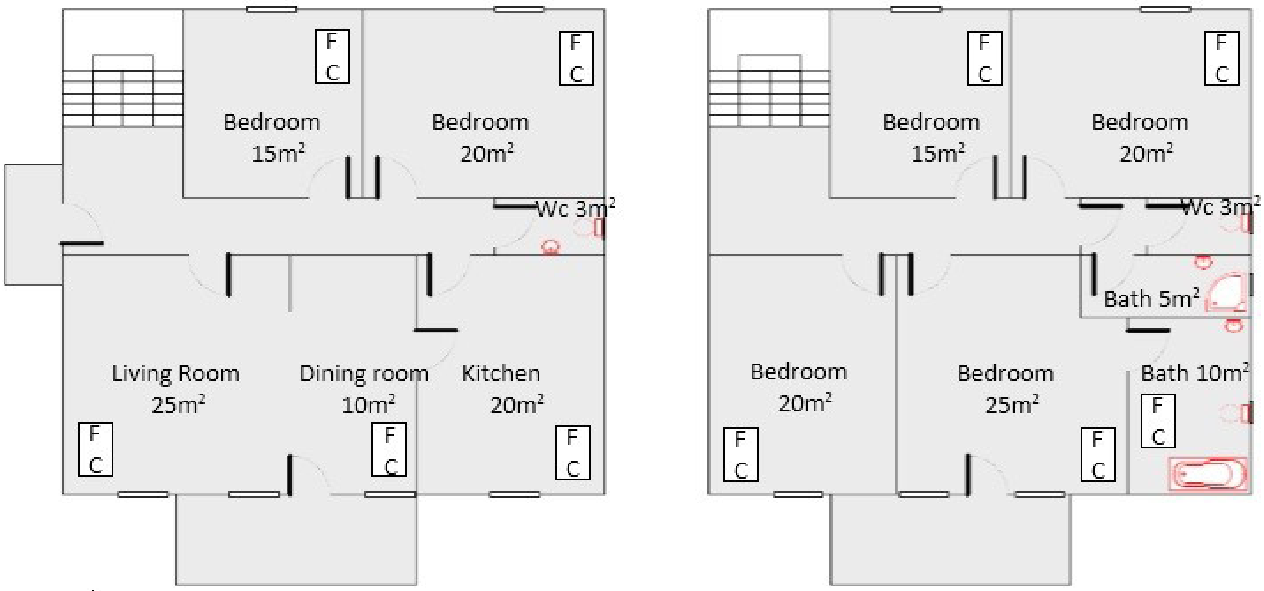

Figure 1. The reference resident plan has been designed for study.

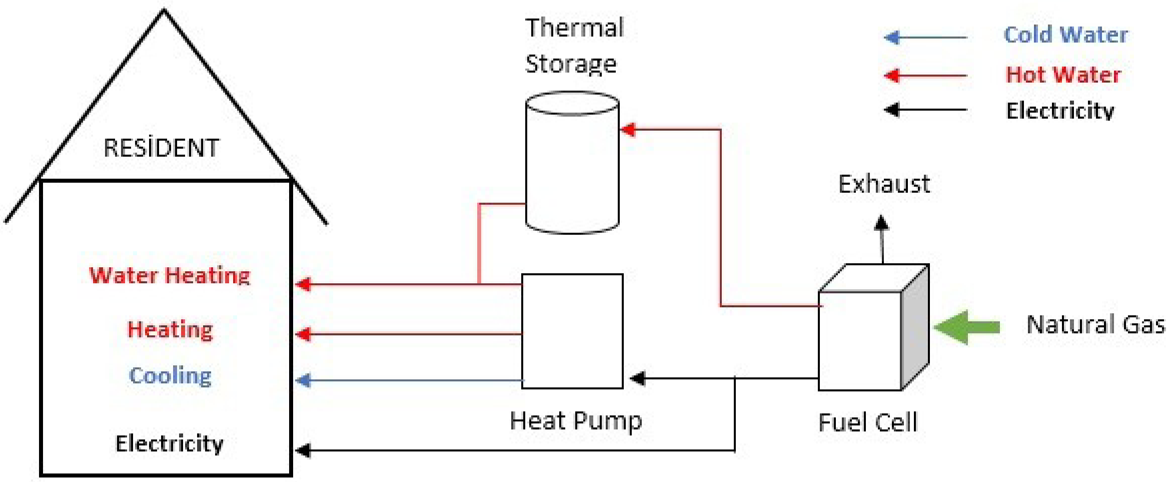

Figure 2. Schematic explanation of fuel cell system implementation and additional system elements.

Comparison results

According to the **Figure 3,** heating loads by climate zones show significant differences. Third and fourth zones illustrates terrestrial climate, so the annual heating requirement for the third and fourth zones is more than first and second zones.

In contrast, cooling has become more important than heating in the first and second zones due to the climate conditions. Since the first and second zones are in moderate climate zones.

Savings characterize differences in operating costs between a conventional system and fuel cell system. The savings are a direct function of the amount of heating and cooling loads (see **Figure 4**). Fuel cell tech-

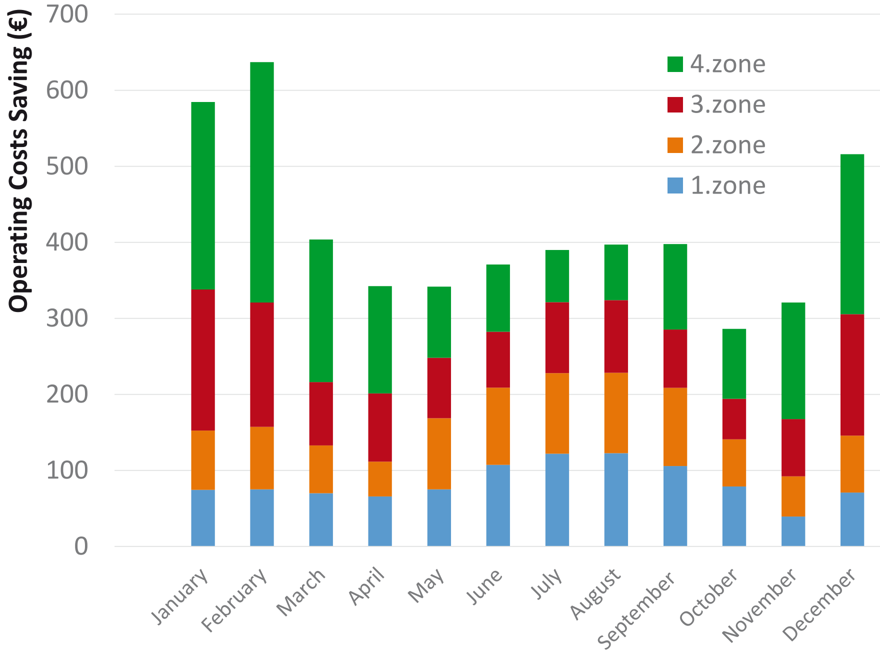

Figure 4. Monthly operating cost savings with fuel cell system in four climate zones, each climatic zone has been shown with one color.

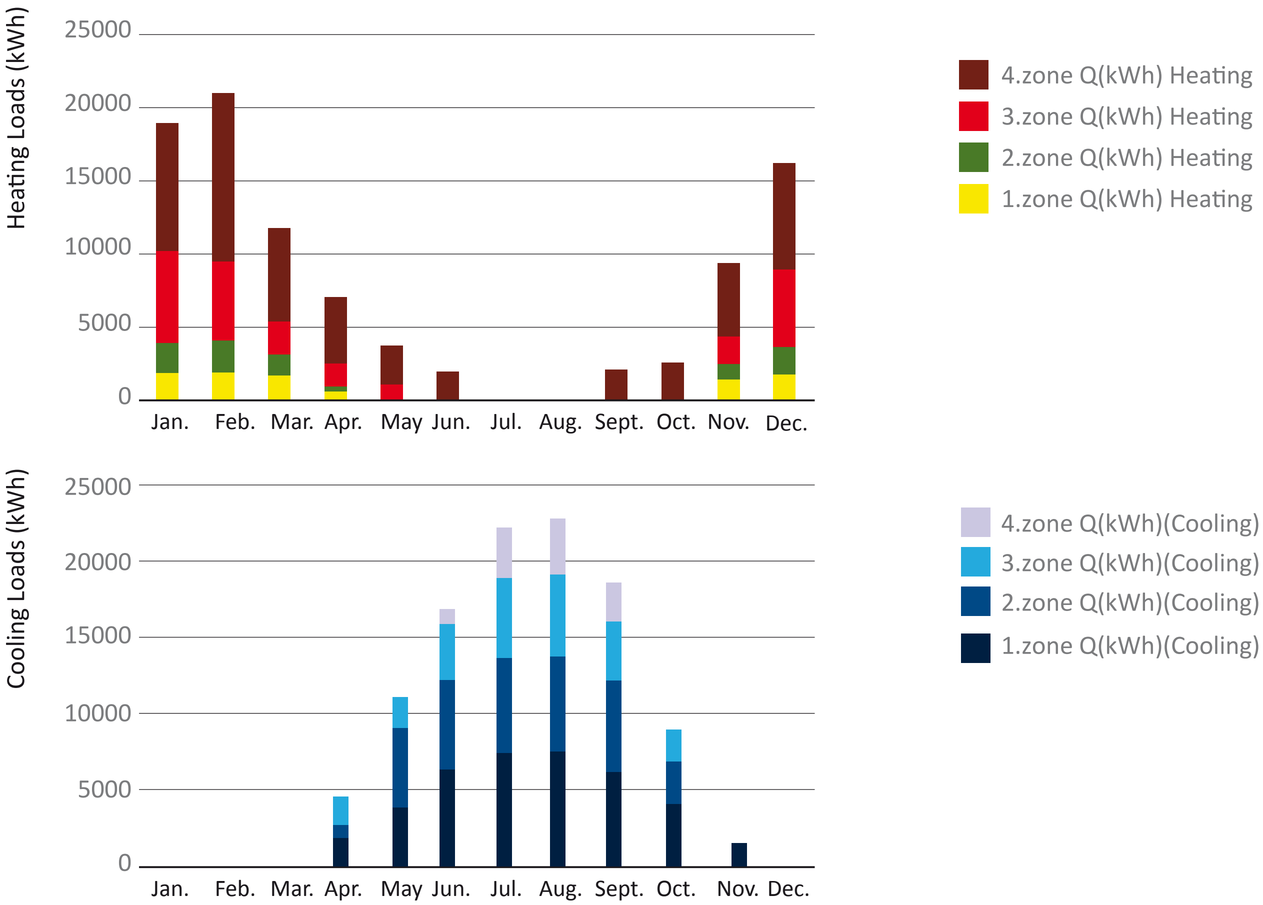

Figure 3. Monthly heating and cooling loads computed with HAP, each climatic zone has been shown with one color.

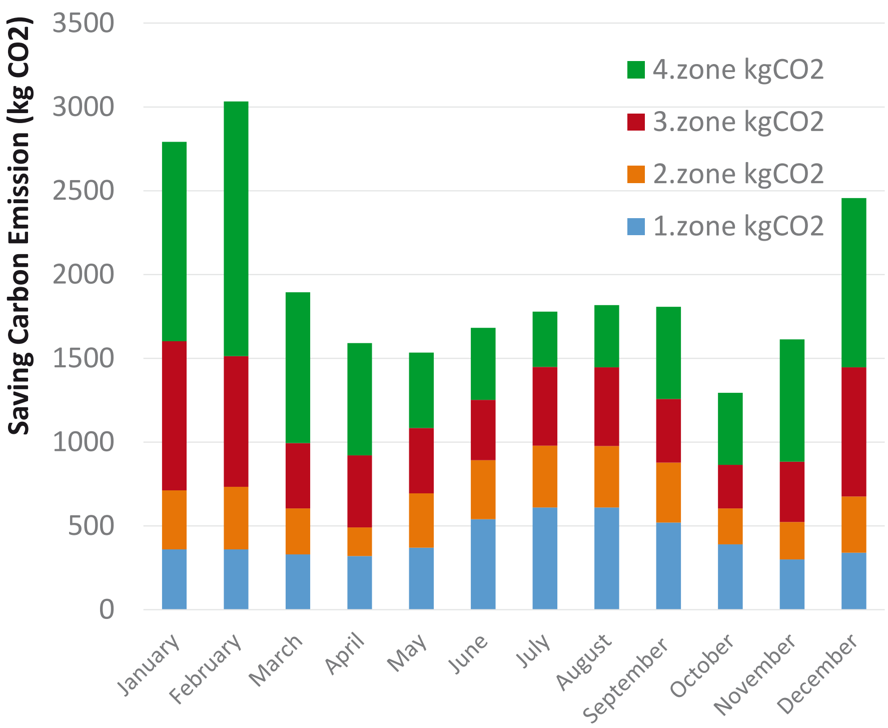

Figure 5. Monthly carbon emission saving values with fuel cell system in four climate zones.

nology is more advantageous in terrestrial climates since heating loads. In moderate climate zones, the advantage of fuel cell system depends on the cooling requirement. Fuel cell systems have provided highly variable financial benefits for domestic applications.

The fuel cell system has an enormous impact on the reduction of carbon emissions (see **Figure 5**). Moreover, carbon emission increases with high heating demand. Therefore, terrestrial climate zones having high heating demand have more carbon emission.

Table 2. Investment costs, operating costs, carbon emission and payback periods have been seen annual and 15-year period.

Climate	System Type	Investment ($)	Operating Cost ($/15years)	Net Present Value ($/15years)	Simple Payback Period ($/year)	Carbon Foot Print (kgCO2/ 15years)	Payback Period
1.zone	Conventional	5110	32937	14190	2196	162300	11,7 years
	FCS	16940	17826	7680	1189	86550	
	Saving	*–11830*	*15111*	*6510*	*1007*	*75750*	
2.zone	Conventional	5110	30930	12990	2063	141990	12,2 years
	FCS	16940	16405	6888	1094	86295	
	Saving	*–11830*	*14525*	*6102*	*969*	*55695*	
3.zone	Conventional	5110	35566	15323	2371	174150	9,6 years
	FCS	16940	17148	7388	1143	84900	
	Saving	*–11830*	*18418*	*7935*	*1228*	*89250*	
4.zone	Conventional	5110	46297	19946	3087	225150	6,6 years
	FCS	16940	19535	8416	1302	96450	
	Saving	*–11830*	*26762*	*11530*	*1785*	*128700*	

The great investment values and also the savings of fuel cell system have been seen for all climate zones in **Table 2**. Consequently, if the payback period is acceptable in terrestrial climates, the same case will be valid in very hot climates. In a moderate climate, the payback period is longer and difficult to implement for the moment.

Equations

$$Bh_g = \frac{Q}{Hu \times \eta} \quad (1)$$

$$Bh_e = \frac{Q}{COP} \quad (2)$$

$$OC = Bh \times t \times UP \quad (3)$$

Where Bh_g is the mean amount, natural gas to be used, Bh_e is the mean amount of electricity to be used and Q is heating or cooling load, Hu is the mean lower heating value of the natural gas, η is the efficiency of the boiler and COP is coefficient of performance. OC is the mean operating cost, t operating time and UP is unit price.

$$NPV = Saving \times \frac{(1+i)^n - 1}{(1+i)^n \times 1} \quad (4)$$

$$SPP = \frac{Saving}{Investment} \quad (5)$$

Where NPV is the mean net present value, i is annual discount rate, n is operating year and SPP is the mean simple payback period.

Conclusion

Overall, energy demand is increasing in the world day to day and domestic applications comprise a large portion of consumption. As a result of this study, more efficient domestic energy applications have become imperative. One of the new technologies is the fuel cell system. In this study, fuel cell system has been applied to a resident and discussed the availability of the fuel cell system.

The fuel cell system is more efficient than conventional system. Operating cost has decreased approximately 50 percent. Another effect is decreasing on the carbon emission value. However, fuel cell systems have a great difficulty for domestic applications. The fuel cell is an expensive technology. In recent years, work on the fuel cell technology has increased and it will be cheaper in near future.

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