A Preliminary Feasibility Study of a Fuel Cell Based Combined Cooling Heating and Power System

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ABSTRACT

Combined cooling, heating and power (CCHP) systems, provide an alternative for the world to meet and solve energy – related problems, such as energy shortages, supply security, emissions, the economy, and conservation of energy, etc. CCHP systems do not just provide electricity and heating but also cooling for space air conditioning or processes. Recent studies points out that the overall efficiencies of CCHP systems that exploit an advanced thermally activated technology are superior to conventional systems. This study is a preliminary feasibility of a fuel cell based combined heat and power (CHP) system coupled with an open cycle desiccant cooling. The technology is based on the principle of outside air dehumidification by an adsorbent. The study shows that the payback time is around 13 years. With governmental and European Union incentives, possible increases in power prices and decreases in costs by mass production the payback time is expected to decrease in the future.

Keywords: CCHP, Desiccant cooling, Sustainability, Fuel cell, Feasibility

Yakıt Pili Bazlı Birleştirilmiş Soğutma Isıtma ve Güç Sistemlerinin Ön Fizibilite Çalışması

ÖZET

Birleşik soğutma, ısıtma ve güç sistemleri (BSIG) dünyada meydana gelen enerji kesintileri, enerji tedarik yetersizliği, , enerji üretimi kaynaklı emisyonlar, enerji tasarrufu ve enerjinin akıllı kullanımı gibi enerji ile ilgili sorunların yönetimi konusunda bir seçenek sunmaktadır. BSIG sistemleri sadece elektrik ve ısıtma sağlamanın yanısıraproseslerin ve ortamların soğutulmasında da kullanılır. Yakın zamandaki araştırmalar göstermiştir ki ileri ısıl aktivasyon teknolojisi ile donanmış BSIG sistemlerinin net verimlilikleri klasik sistemlerden daha üstündür. Bu çalışmada, yakıt pili bazlı birleştirilmiş ısıtma güç sisteminin açık çevrimli desikatör soğutma sistemi ile birleştirilmesinin ön fizibilite çalışması sunulmuştur. Söz konusu sistemin teknolojisinin prensibi adsorbent tarafından dış havada bulunan nemin tutlmasına dayanmaktadır. Çalışmanın sonucunda başabaş noktasına ulaşma süresi 13 sene olarak bulunmuştur. Kamu ve Avrupa Birliği'nin bu sistemlere vereceği teşvikler, enerji maliyetlerinde olacak olası artışlar ve seri üretime geçilmesiyle bu sistemlerin maliyetlerinin düşmesiyle bu sürenin yakın gelecekte kısalması beklenmektedir.

Anahtar Kelimeler: CCHP, Desikatör soğutma, Sürdürülebilirlik, Yakıt pili, Fizibilite

1. INTRODUCTION (GİRİŞ)

A big proportion of the world's energy demand caused by built environment. In Turkey, the commercial buildings consume about one-third of the total energy produced is at [1]. Fully air-conditioned office buildings are important energy end-users since mid 90s [2]. Reduction of energy use in space air conditioning will be a key feature of energy saving and environmental protection in Turkey.

Energy performance, which is one of the important aspects of energy conscious design, needs greater attention especially for office buildings [2-4].

As a derivation of combined heat and power (CHP, also called cogeneration) systems – a proven and reliable technology with a history of more than 100 years – combined cooling, heating and power (CCHP) systems, provide an alternative for the world to meet and solve energy – related problems, such as energy shortages, supply security, emissions, the economy, and conservation of energy, etc. Especially fuel cell based systems are very attractive as decentralized energy resources (DER), since they are quiet, efficient and environmentally friendly way to produce electricity, heating, and cooling [5-7].

The most important difference between CCHP systems and conventional cogenerations is that CCHP systems do not just provide electricity and heating but also cooling for space air conditioning or processes. As CCHP systems can utilize traditional cooling and dehumidification systems coupled with a traditional CHP, it is also possible to employ advanced thermally activated technologies. Recent studies point out that the overall efficiencies of CCHP systems which exploit an

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advanced thermally activated technology are superior. Other than the high primary fuel efficiency, low emissions and net cost reduction also can be accomplished by the utilization of thermally activated technologies [5].

There are several types of thermally activated technologies such as absorption chillers, adsorption chillers and desiccant dehumidifiers etc. This work aims to analyze the feasibility of a fuel cell based CHP system coupled with an open cycle desiccant cooling by realizing a preliminary feasibility.

2. SYSTEM DESCRIPTION (SİSTEMİN TANIMLANMASI)

2.1 Load Analysis (Yük Analizi)

The selection of proper size and operating mode of the prime mover for the energy system depends on the thermal and electrical loads of building [9].

For a thorough matching, these loads are needed on an hourly, daily, monthly, and yearly basis. However, in this preliminary study only the highest loads for yearly basis are calculated by the means of average weather data and simplifications of the buildings features.

2.1.1. Weather Data (Meteorolojik Veriler)

The key climatic variables affecting the thermal loads for building design and energy use analysis include dry bulb, wet bulb, wind speed, wind direction, and solar radiation.

In this study, the average temperature and relative humidity data taken from National Meteorological Institution were used [10].

2.1.2. Description of the Building (Binanın Özellikleri)

The building studied is a six floor office building located in Ankara with the rough dimensions of 15m x 15m x 20m. External walls have an overall U-value of 2.86 W/m^{2}K. The window to wall ratio accepted as 40% and the windows overall U-value is 5.82 W/m^{2}K.

2.1.3. Cooling and Heating Load (Soğutma ve Isıtma Yükleri)

Cooling and heating loads of the building are calculated by the methodology described by Özkol, which is based on heat transmission, infiltration and ventilation losses [11]. The thermal energy needed to meet the cooling load in the warm months and heating load in the cold months of the building calculated as 107 kW and 112 kW respectively.

2.1.4. Power Load (Güç Yükü)

The electricity consumption of office buildings in Europe are between 48 - 85 kWh/m^2·year [3]. In the analysis, the power load of the building assumed to be 35kW without A/C.

2.1.5 Analysis and Prime Mover Selection (Analiz ve Ana Kuvvet Seçimi)

There are several types of fuel cell based CCHP prime movers available on the market with different heat-to-power ratios. Heat-to-power ratios of fuel cells vary between 0.9 and 1.1.

There are various options to match the electrical power and thermal demand of the building with a prime mover. Figure 2.1 shows electrical power as a function of thermal energy. The diagonal lines are the heat-to-power characteristics of some fuel cell systems available on the market. Electrical power and thermal energy demands of the building are shown as the horizontal and vertical lines, respectively.

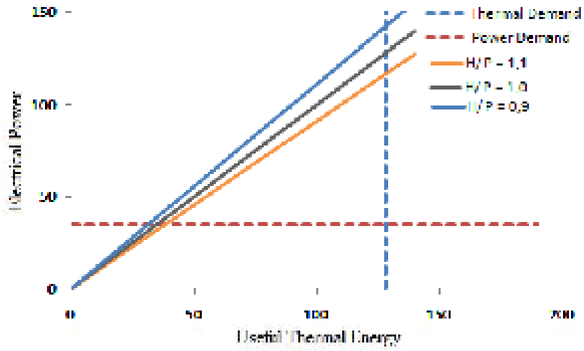

Figure 2.1. Prime mover selection.

Electrical power demand or thermal energy demand can be chosen as the base for the operation mode. If the electrical power demand chosen as base then supplementary boilers should be used to supply the additional thermal energy, If the thermal energy demand is chosen as the base then there will be excess electrical power which may be sold to an external customer such as electrical utility company. For both options having a high heat-to-power ratio is essential.

In this study 1.1 heat-to-power ratio and thermal energy based operation mode is selected.

3. OPEN CYCLE DESICCANT COOLING (AÇIK ÇEVRİMLİ DESİKANT SOĞUTMA)

Desiccant cooling systems (DCS) are an established know-how for air-conditioning buildings, mainly suitable for the applications of solar thermal energy, and CHP systems with low waste heat temperatures, due to the low temperature demands of around 60–80°C [4]. The technology is based on the principle of outside air dehumidification by an adsorbent such as silica gel or LiCl. After pre-cooling, the dried air with maximally humidified room exhaust air subsequent evaporative cooling produces the desired supply air temperatures of 16 – 18 °C The desiccant cooling process can be continuously operated with slowly rotating sorption wheels, where the outside air humidity taken up in the adsorbent is transferred to the exit air heated by waste heat from a low temperature heat source like a polymer electrolyte fuel cell. [8]

3.1. Desiccants (Desikantlar)

Desiccants are widely used to control the humidity by absorbing moisture from the atmosphere. They have a high affinity for water. During the absorption process, a heat of adsorption is released, which is equals to the latent heat of vaporization, so the output dry air is at a higher temperature than the input air. A desiccant that has adsorbed moisture can be regenerated by bringing it into contact with air of low relative humidity. There are several types of desiccants such as silica gel, activated carbon, LiCl, etc [12]. Silica gel, which is a solid desiccant, embedded in a sorption wheel is considered as dehumidification material is chosen for the system being analyzed.

3.2. Sorption Wheel (Sorpsiyon Tekeri)

Sorption wheels are slowly rotating hygroscopic storage masses that are flowed through on one side by outside air and on the other by heated regeneration air. Figure 3.1 is a schematic representation of a sorption wheel.

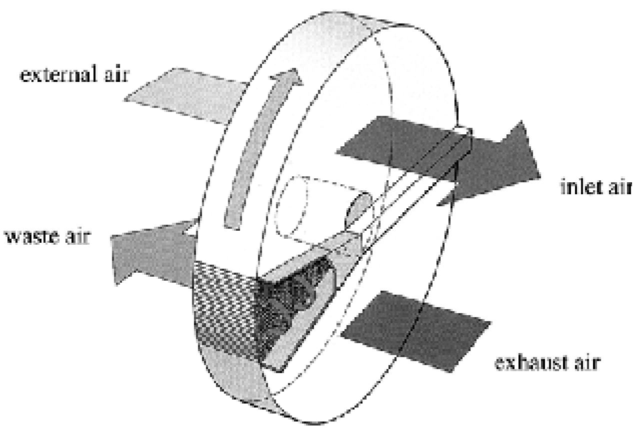

Fig 3.1. Schematic representation of a sorption rotor [4].

As solid sorption materials, silica gel, and hygroscopic salts such as lithium chloride are commonly used. They are applied in continuously operating systems to a rotating substrate or used as fixed bed systems for intermittent operation. Typical dehumidifying performances at regeneration temperatures of 70°C are around 4–6 g/kg of dry air. [8]

To obtain optimal dehumidifying performance, the number of revolutions of the sorption wheel must be adapted to the regeneration air temperature and to the respective humidity conditions. Too high regeneration temperatures warm up the rotary sorption wheel after desorption so strongly that the sorption material at first can hardly take up moisture on the supply–air side, but has to be cooled down first (so-called heat inhibition) [4].

3.3. Working Principle of Open Cycle Adsorption Cooling (Açık Çevrimli Absorpsiyonlu Soğutmanın Çalışma Prensibi)

The temperature of outside air increases while being dried in the sorption wheel. Then the air goes into the heat exchanger where it meets the returned air which is cooled by the humidifier and pre-cooled. Then by evaporative cooling it is set to desired temperature. Figure 3.2 shows the operating principle of cycle desiccant cooling.

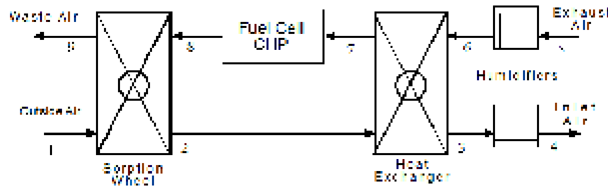

Fig 3.2. Open cycle desiccant cooling working principle.

The returned air coming from the conditioned space is cooled down as much as possible by the means of humidification. Then it cools the process air in rotating heat exchanger. After getting heated up to the necessary regeneration temperature of the desiccant in air heater, which in this study is the cooling of fuel cell, goes to the sorption wheel to regenerate the desiccant by taking the moisture from it.

Thermodynamical statuses of the air flows are determined by using the mollier diagram (Figure 3.3). The mass flow of air needed is calculated using the heat load and thermodynamical data for feed air to the conditioned space. The size of sorption wheel, humidifiers, heat exchanger and blower are selected according to the mass flow of feed air.

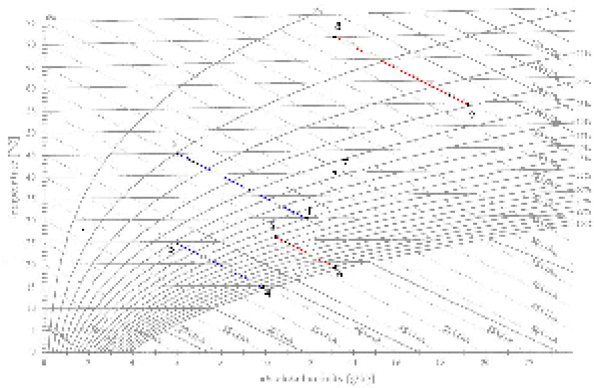

Fig 3.3. Mollier diagram of the system [8].

4. FUEL CELL BASED CHP SYSTEM (YAKIT PİLİ BAZLI BİRLEŞTİRİLMİŞ ISITMA GÜÇ SİSTEMLERİ)

Fuel cells are compact, quite power generators without moving parts that creates electrical energy by the means of electrochemical reaction of hydrogen and oxygen.

The fuel cell based CHP system selected for this study has a PEM fuel cell with a nominal capacity of 100kWel, a fuel processing unit, which reform natural gas and 1.1 heat-to-power ratio.

5. FEASIBILITY STUDY (FİZİBİLİTE ÇALIŞMASI)

A feasibility study was carried out to analyze the potential impact of the proposed project. In this feasibility study technical development and project implementation was preceded. The assessment was based on an outline design of system requirements in terms of capital costs and operational costs in order to estimate whether the new system will be feasible or not. Technological feasibility, which is not taken into consideration in this study, can also be carried out to determine whether a specific company has the capability, in terms of software, hardware, personnel and expertise, to handle the completion of the project.

Economic analysis was chosen for being the most frequently used method for evaluating the effectiveness/feasibleness of a new system. More commonly known as cost/benefit analysis. Cost based study was taken into account by identifying the cost factors, which can be categorized as follows: 1) Capital costs 2) Operational costs.

As it seen in Tables 1 and 2 the installation costs of the fuel cell based CHP system and open cycle desiccant cooling are much higher than the conventional systems. In the other hand, the operational, maintenance, and fuel costs are less than the conventional systems electricity even when the electricity sold to the utility company included [6,8,13 – 15]. The system will pay itself back in approximately 13 years.

Table 1. Capital costs comparison

Capital Costs (€)	
CHCP Total	342.500 €
FC based CHP	257.000 €
Desiccant cooling	85.500 €
Conventional System Total	23.000 €
Boiler system for heating	7.000 €
AC	16.000 €

Table 2. Operational costs comparison

Operational (€/year)	
CCHP Total	20.350 €
FC based CHP maintenance	5.900 €
Desiccant cooling maintenance	1.250 €
Fuel Cost	31.100 €
Avoidance by selling electricity	17.900 €
Conventional System Total	45.500 €
_Fuel cost for heating	22.900 €
_Electricity (Including A/C)	22.600 €

6. CONCLUSIONS (SONUÇLAR)

The results can be summarized as follows:

- The system investigated pays itself back in 13 years. Probable and effective rises in the energy costs might cause a more rapid payback in the imminent future.
- Fuel cell systems are not mature enough to be used as prime movers in CCHP applications.
- No incentives were taken into account when comparing the capital costs. Government incentives may improve the payback time.
- Selling of excess electricity is essential for encouraging the investors. Without electricity buying of the government, the payback of the systems takes approximately 16 years, which is economically unacceptable.
- Using fuel cell based CCHP systems might be a great help to Turkey on meeting the demands of the newly signed Kyoto Protocol.
- Open cycle desiccant cooling is not enough for places with high relative humidity, the system needs an auxiliary unit such as Absorption chiller.

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