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***Research Article***

# Investigation of the Temperature Distribution of a Small Solar Chimney

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**Abstract**

Environmental friendly and sustainable energy policies are gaining importance day by day. A prototype solar chimney constructed in Elazig is investigated experimentally in terms of temperature distribution and solar chimney efficiency. Elazig is in the third degree day region where the temperature varies between -15 ° C and + 42 ° C. The experimental results showed that the efficiency depends on height of the chimney and the temperature of ambient. The higher the height of the chimney, the more is the efficiency. However, the effect of ambient temperature on the efficiency seems to be very low. It was seen that, solar chimney system can be an alternative system for energy production under Elazig conditions.

**Keywords:** Solar energy, Solar chimney power plants, Efficiency.

# Küçük Bir Güneş Bacasının Sıcaklık Dağılımlarının İncelenmesi

**Öz**

Çevre dostu ve sürdürülebilir enerji politikaları gün geçtikçe önem kazanmaktadır. Elazığ'da yapılan prototip bir güneş bacası, sıcaklık dağılımı ve güneş baca etkinliği açısından deneysel olarak incelenmiştir. Elazığ, sıcaklığın -15 ° C ile + 42 ° C arasında değiştiği üçüncü derece gün bölgesindedir. Deneysel sonuçlar, güneş baca yüksekliğinde bir artışla verimliliğin arttığını göstermiştir. Verim, baca yüksekliğine ve ortam sıcaklığına bağlıdır. Baca yüksekliği ne kadar yüksek olursa verimlilik o kadar fazla olur. Bununla birlikte, ortam sıcaklığının verimlilik üzerine etkisi çok düşük görünmektedir. Güneş baca sisteminin Elazığ şartlarında enerji üretimi için alternatif bir sistem olabileceği görülmüştür.

**Anahtar Kelimeler:** Güneş enerjisi, Güneş bacalı güç sistemleri, Verim.

## 1. Giriş

Today, about 75% of global energy consumption is provided from fossil fuels that cause climate change and various environmental problems. (Jamali et al., 2019). It is estimated that, the current world energy requirements can be supplied by renewable energy by more than 3000 times with more than 93% from solar energy (Ellabban et al., 2014).

Due to its geographical location, Turkey has a better chance compared to other countries in terms of its solar energy potential. Turkey has an average annual time of 2640 hours (7.2 hours per day) and an average annual solar radiation of 1311 kWh/m²-year (3,6 kWh/m² per day) (EİE, 2006). Since solar energy is an inexhaustible and inexpensive source of energy and does not harm the environment, the use of solar energy is becoming more common.

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The idea of the solar chimney was first introduced by Schlaich in the late 1970s. Then, the construction of a pilot plant in Manzanares, Spain was started. This pilot plant with a power capacity of 50 kW has produced electricity for 7 years.

Increasing use of solar energy has been effective in the development of solar chimney technology in recent years. A solar chimney system typically comprises of three important components, a chimney, a solar collector, and a turbine.

A solar chimney power plant was analyzed in the Arabian Gulf region (Hamdan, 2011). The analysis indicated the most essential physical factors for the design of a solar chimney are the height of the chimney and the turbine pressure head.

An improved solar chimney concept to produce electricity with low-grade heat in thermal power plants was performed by Ghorbani et al. (2015). Their results indicate a maximum of 0.538% rise for the thermal efficiency of the power plant with fossil fuel.

A simulation for the full-year power capacity of a conventional and a sloped solar chimney power plant with maximum solar radiation angle and maximum power generation angle were performed by Cao et al. (2018). It was concluded that the two important factors which influence the sloped solar chimney power plant's power capacity and accumulated power generation were the temperature rise of the air in the solar collector and the system height.

Prakash et al. (2019) made some design configurations for conventional solar air heaters to improve the thermal efficiency. Among the designs investigated, the highest average value of thermal efficiency of 16.5% was achieved by the forced induced glazed air heater with fins in solar chimney.

Solar chimneys were also used for cooling purposes (Jamali, 2019). Jamali et al. (2019) investigated a solar chimney for cooling a semi-transparent photovoltaic power plant for five different cities with various climates, thermally and economically.

There are studies investigating the effects of ground materials (Al-Azawie et al.,2014), wind speed and direction (Aja et al. 2013), the usage of phase change materials (Li and Liu, 2014), geometrical effects (Kasaeian A. 2014, Ming et al. 2013) and air humidty (Ninic 2006) on the performance of solar chimneys. An updated review on solar chimneys has been provided by Kasaeian, 2017.

In this study, a solar chimney was constructed in Elazig in the third degree day region of Turkey. The temperature distribution and power generation of the system is investigated experimentally.

# 2. Material and Method

## 2.1. Experimental Set-Up and Procedure

Solar chimney is a thermal system developed to obtain electrical energy from solar energy. There are three basic principles in the solar chimney system. These are greenhouse effect, chimney draft generated by the difference in density and temperature, and the kinetic energy.

A solar chimney system typically comprises of three main parts, a solar collector, a chimney and a turbine. Solar radiation collected by the solar collector and the greenhouse effect to warm up the air below the transparent collector roof are used by the system. A large pressure difference occurs between the system and the ambient air because of a temperature and consequently a density difference between the inside and outside of the chimney and this drives the wind turbine settled in the chimney for generating electricity. A prototype solar chimney plant was constructed and mounted on the flat roof of Mechanical Engineering Department of Firat University in Elazig, Turkey. Schematics and the assembly of the solar chimney are shown in Figure 1 and 2, respectively.

The collector, which was made of glass, has a diameter of 3.5 m. The chimney's height is 3 m and diameter is 0.2 m. The dimensions and the measurement points are given in Figure 1. A turbine was placed into the chimney. Thermocouples were mounted at the different measurement points of collector and along the chimney. The voltage and current measurements were provided by a voltmeter. The experiments were conducted on May 2017.

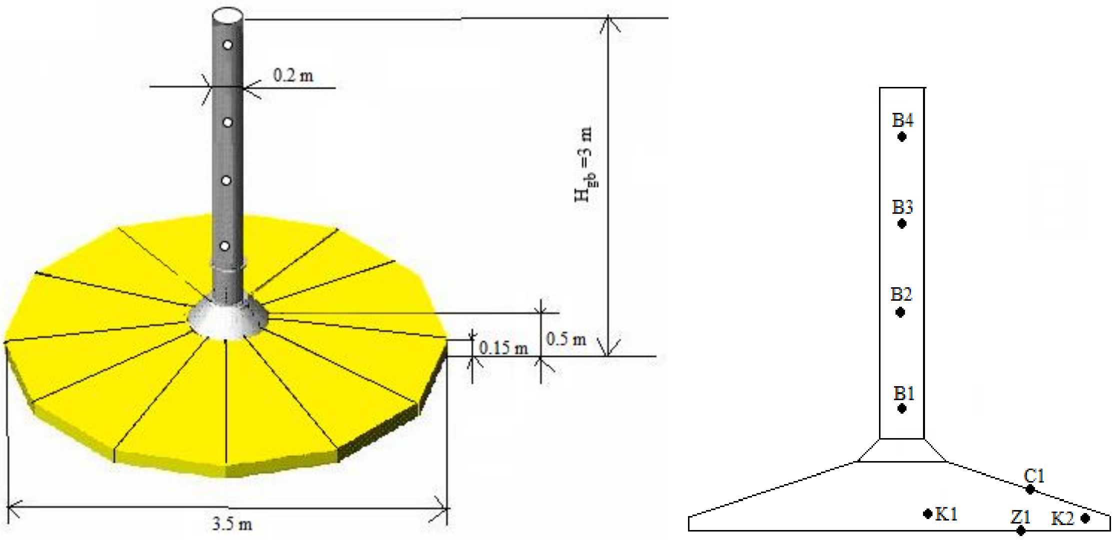


**Figure 1.** Schematics of the Solar Chimney (a) Dimensions (b) Measurement points

**Figure 2.** Assembly of the solar chimney

## 2.1. Teorical Model

In general, the output power of the solar chimney is calculated by multiplying the solar energy entering the system with total efficiency (Schlaich et al., 2005):

$$P = Q\,\eta_{tot} \tag{1}$$

Here; P is the output power of the solar chimney. Solar energy entering the system and the total efficiency are represented by Q and $\eta_{top}$, respectively. The total efficiency consists of collector, chimney and turbine efficiencies. If equation (1) is rearranged (Schlaich et al., 2005),

$$P = Q\,\eta_{col}\,\eta_{ch}\eta_{tr} \tag{2}$$

Here, $\eta_{col}$, $\eta_{ch}$ and $\eta_{tr}$ are collector efficiency, flue efficiency and turbine efficiency, respectively. Collector efficiency can be determined as below (Parthasarathy and Pambudi, 2019).

$$\eta_{col} = \frac{\dot{m}\,c_p\,\Delta T}{A_{col}\,I} \tag{3}$$

where η and m are the collector efficiency and air mass flow rate (kg/s), respectively. $c_p$ represents the specific heat capacity of the hot air (kJ/kg K) while the temperature difference between the hot air and ambient air is represented by ΔT (K). $A_{col}$ and I are the solar collector area (m$^2$) and radiation intensity (W/m$^2$), respectively.

Using the equation below the mass flow rate (m) can be calculated (Parthasarathy and Pambudi, 2019).

$$\dot{m} = \rho\, A\, v \tag{4}$$

where ρ indicates the density (kg/m$^3$), A and v represent the outlet hot air vent area (m$^2$) and hot air velocity (m/s), respectively.

Solar chimney's efficiency can be determined from (Schlaich et al., 2005)

$$\eta_{ch} = \frac{g\, H_{ch}}{c_p\, T_0} \tag{5}$$

Here, the gravitational acceleration is indicated by g. $H_{ch}$ is the chimney height and $T_0$ is temperature of ambient.

Assuming that the air flow in the chimney is uniform, the maximum air velocity in the chimney can be calculated as,

$$V_{ch,max} = \sqrt{2\, g\, H_{ch}\, \frac{\Delta T}{T_0}} \tag{6}$$

where ΔT is the temperature difference between the chimney entrance (collector exit) and the ambient.

# 3. Results

Fig. 3 shows hourly variations of the solar radiation for Elazığ city. The maximum solar radiation is found at maximum value at 13:00 PM and recorded a value of 539.76 W/m$^2$. The temperature variation along the chimney with time is given in Figure 4. As can be seen from the figure, the temperature along the height of the chimney ranges from 29 to 40 ° C and reaches the maximum value at 11:50. The measurements, at the same day at specified hours at the specified points and heights showed that temperature at B1 point reaches the maximum value.

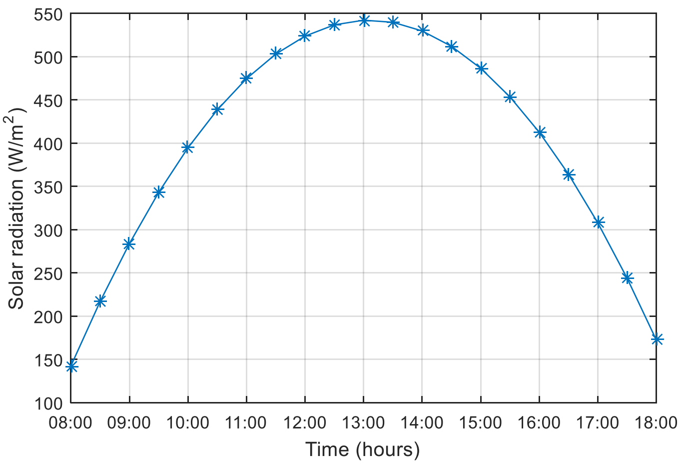


Fig. 3. Hourly variation of solar radiation for Elazığ.

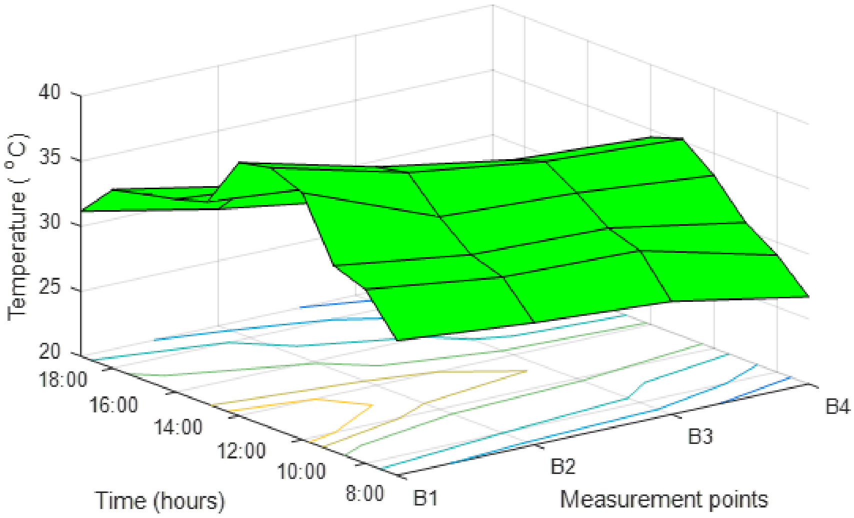


Figure 4. The temperature variation along the chimney with time

Figure 5 and 6 show the temperature distribution inside the collector, at the glass and floor and temperature variation at all measuring points with time, respectively. The lowest temperature in the collector is measured as 29.1ºC while the highest one is 40.2 ºC. As can be seen from the figures an increase in solar radition causes an increase in the temperature of measured points. It is seen that the ground temperatures rises to 50 ºC and the glass temperature rises to 46.5ºC.

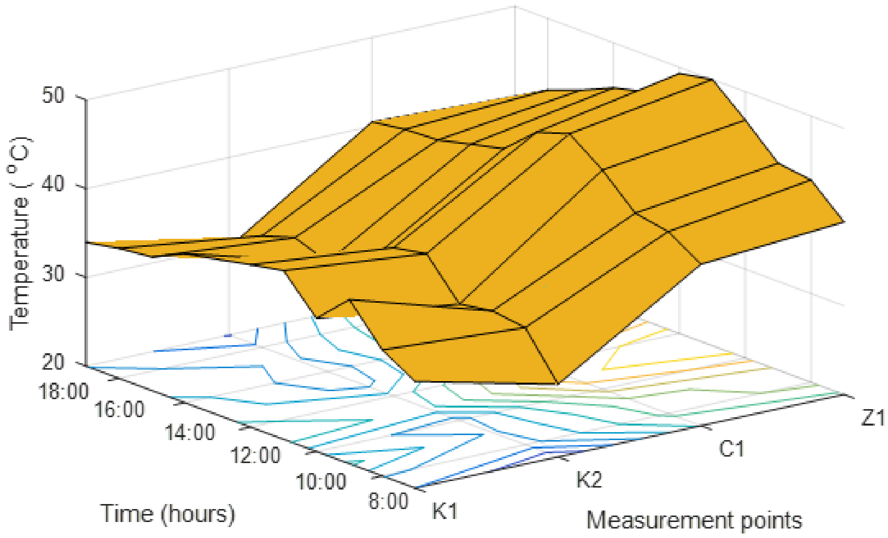


Figure 5. The temperature variation in the collector, at the glass and ground with time

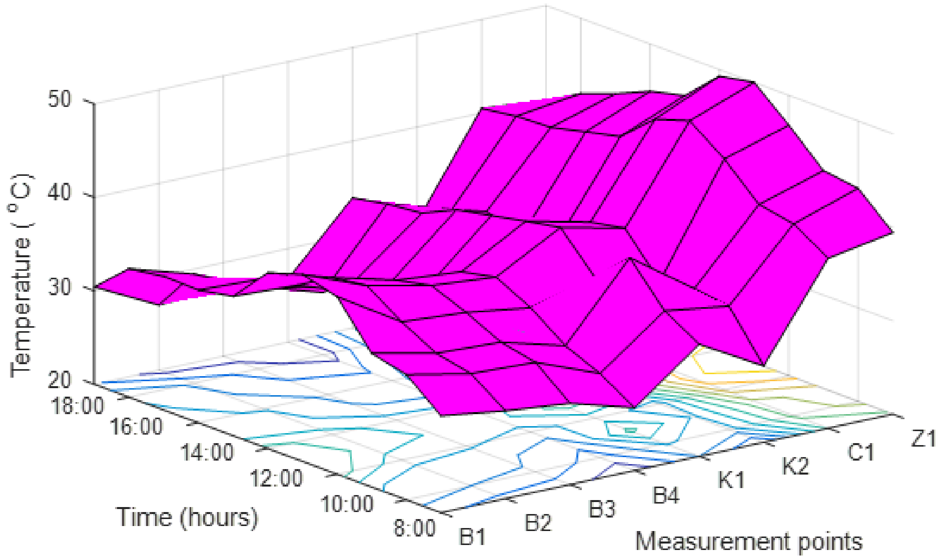


Figure 6. The temperature variation at all measurement points with time

Figure 7 shows the velocity change with time along the chimney. It is seen that the velocity increases with time. The rise of the heated air in the collector is directly proportional to the temperature increase in the collector and the diameter and the chimney height. The air in the collector flows from the collector into the vertical chimney and then discharged to the environment because of the density difference between the heated air in the collector and the ambient air. Therefore, as the solar radiation to the collector increases, the air temperature in the chimney increases because of the temperature increase of the air in the collector.

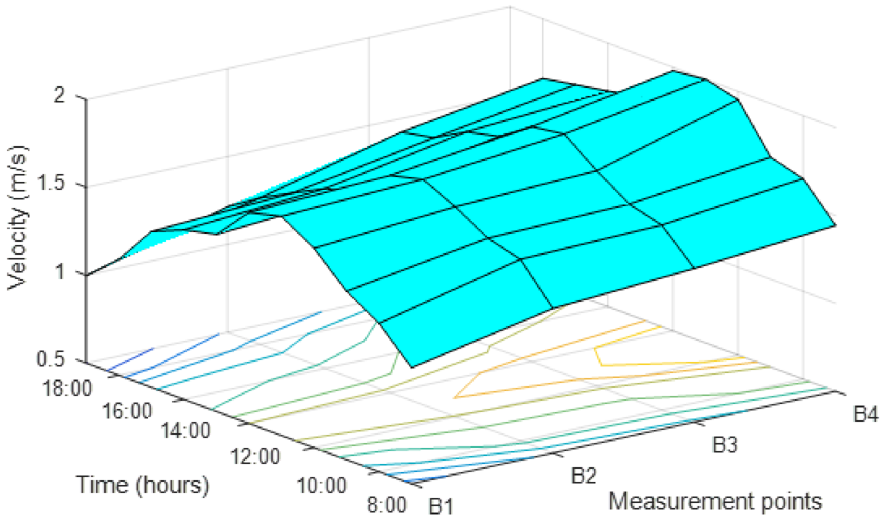


Figure 7. The velocity variation along the chimney with time

The variation of the solar chimney efficiency with the chimney height and ambient temperature is given in Figure 8. The efficiency depends onthe chimney height and the ambient temperature. The higher the height of the chimney, the more is the efficiency. However, the effect of ambient temperature on the efficiency seems to be very low.

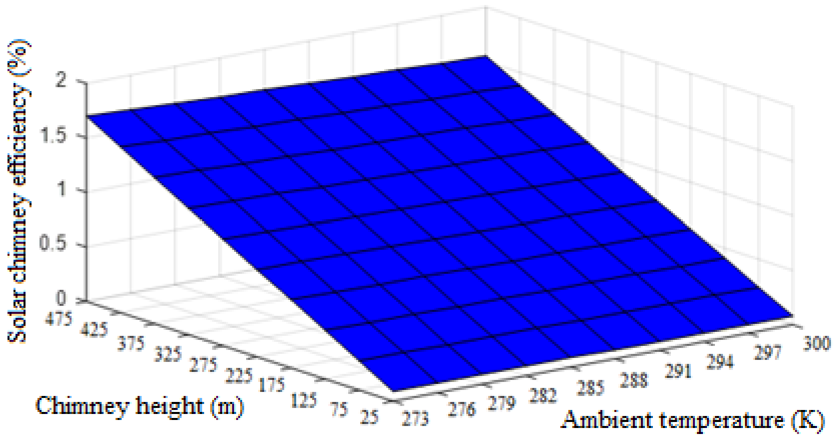


Figure 8. Variation of solar chimney efficiency with chimney height and ambient temperature

# 4. Conclusion

With the increasing sensitivity to environmental pollution in the world, there are constantly new searches to meet the increasing energy needs. Solar chimney power plants make positive environmental and economic contributions to the reduction of fossil fuel use through solar energy. In this study, thermal performance of a prototype solar chimney established in the campus area of Firat University was investigated. The experimental results showed that efficiency increased with an increase in the height of the solar chimney. Besides, the velocity of the air in the chimney increased due to the increase in temperature in the solar collector. Elazig is a city in eastern Anatolian which has an annual average radiation intensity of 1365 kWh/$m^2$ and has 2664 hours sunshine duration. Therefore, solar chimney system can be an alternative system for energy production under Elazig conditions and a solar chimney power plant can be established in this region.

## Nomenclature

| | |
|---|---|
| A | outlet hot air vent area ($m^2$) |
| $A_{col}$ | solar collector area ($m^2$) |
| $c_p$ | specific heat capacity of the hot air (kJ/kg K) |
| $H_{ch}$ | chimney height (m) |
| I | radiation intensity (W/$m^2$) |
| $\dot{m}$ | air mass flow rate (kg/s) |
| P | output power of the solar chimney (Pa) |
| v | hot air velocity (m/s) |
| $V_{ch,max}$ | maximum air velocity in the chimney |
| $T_0$ | temperature of ambient (K) |
| ΔT | temperature difference |
| ρ | density (kg/$m^3$) |
| $\eta_{top}$ | total efficiency |
| $\eta_{col}$ | collector efficiency |

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