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Study of efficiency of turbines with differing diameters of solar chimney energy systems

Yasin İçel*[1], Abdulcelil Buğutekin[2a] and Mehmet S. Mamiş[3b]

[1]Department of Electrical and Energy, TBMYO, Adıyaman University, Altınşehir Mah. 3005 Sok. No:13 02040 Adıyaman, Turkey
[2]Department of Mechanical Engineering, Engineering Faculty, Adıyaman University, Altınşehir Mah. 3005 Sok. No:13 02040 Adıyaman, Turkey
[3]Department of Electrical and Electronics Engineering, Engineering Faculty, İnönü University, Central Campus, Elazığ Road, 15. km 44280 Malatya, Turkey

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Abstract. Solar Chimney Power Plants (SCPP) consist of three main components: solar collector, chimney and turbine. Air under the collector is heated by the greenhouse effect, the air density is reduced and the air flows toward the chimney located at the center of the collector. Thus, electricity is produced at the turbine mounted at the entrance of the chimney. In this study, measurements have been carried out on the Solar Chimney Power Plant (SCPP) system built at Adıyaman University Campus area, with specifications 15 m in height, 0.8 m in diameter of chimney, 0.004 m thick transparent glass floor and a collector having maximum of 27 m in diameter. For this purpose, air flow rate and temperature in the chimney at certain times of the day, ambient temperature, ambient wind speed, ground temperature heated by the greenhouse effect of the collector, temperature and air velocity under the collector, the number of revolutions of turbines of different diameters and Adıyaman solar radiation values were evaluated. In this study, it has been determined that solar radiation, ambient temperature, chimney height and diameter, solar radiation absorption rate of the ground under the collector are the parameters that affect the efficiency performance of the system. It is also observed that temperature and air velocity at the point where the turbine assembly is located are maximum. In addition, it was determined that the turbine model with a diameter of 0.8 m was the most efficient model for the system. It is concluded that Solar Chimney Power Plant (SCPP) can be considered as alternative energy sources for Adıyaman.

Keywords: efficiency; solar chimney power plants; solar power; wing models

1. Introduction

Depending on the rapid increase in the population of the earth and that of life quality, the global need for energy will have approximately tripled by 2050. However, this increased energy need can’t be provided sufficiently with present conventional energy sources (Quaschning 2005). Not being able to meet the need for energy causes the gap between the production and consumption of energy to increase rapidly. In that case, to meet the increasing energy hunger in our country, it is primarily

*Corresponding author, Assistant Professor, E-mail: yicel@adiyaman.edu.tr
[a]Professor, E-mail: abugutekin@adiyaman.edu.tr
[b]Professor, E-mail: mehmet.mamis@inonu.edu.tr

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necessary for us to utilize effectively and rationally the renewable energy sources (Chamber Report 2022). In addition, traditional energy production methods are the primary cause of pollution. One other advantage of renewable energy sources is that they give very little damage to the environment during energy production. Expanding renewable energy is set to offset the use of natural non-renewable resources for electricity generation, which have caused environmental crises, such as atmospheric pollution, climate change and depletion of stock resources (Mirza and Abedi 2020, Papadopoulos *et al.* 2022). Electricity production from solar power is done by two methods, which are applied either directly (photovoltaic) or indirectly (solar chimney, etc). The idea of Solar Chimney was first proposed by the German researcher Hanns Günther in 1931 (Yabuz 2009, Xinping *et al.* 2007a, Schlaich 2005). Later, the solar chimney was designed by Prof. Dr. Jörg Schlaich towards the end of the 1970s, and the first concept solar chimney was designed by Prof Dr Jörg Schlaich in 1978 (Yabuz 2009). This prototype had a collector of 122 m in diameter and a chimney of 194.6 m height and 10 m diameter. The highest output rate that the system achieved was 41 kW during the period from July to September in 1982 (Yabuz 2009, Xinping *et al.* 2007a). In the following years, many researchers worldwide started to make researchers on the solar chimney system.

American scientist Krisst built a solar chimney of 10 W power at the courtyard of his house. The collector diameter and the height of this system are respectively 6 m and 10 m (Yabuz 2009, Xinping *et al.* 2007a). Pasumarthi and Sherif has investigated the performance traits of solar chimneys both theoretically and experimentally in 1998 (Mekhail *et al.* 2017). A Mathematical model has been developed in order to examine parameters like the temperature of the medium and power output. In 2002, John Gannon examined the model of the collector and the turbine in detail. Gannon obtained the heat equation and he used a constant heat conduction coefficient, which is 5 W/m^2 K (Koyun 2006, Gannon 2002). Through this value, a solar chimney with a diameter of 2000 m has been calculated. In addition, bottom temperature has been concluded to reach 68 °C at most. The reason for the bottom temperature to be so high is the lack of a heat storage system and the usage of a constant heat conduction coefficient.

In 2003, Bernardes *et al.* made studies, analyses and publications over analytical and numeric models for the output power of the chimney by using the relations between output power, facility dimensions and several environmental factors (Bernardes 2003). The studies have shown that the height of the chimney, the pressure drop across the turbine, diameter of the collector and its optic properties are important parameters in the design of a solar chimney. Several researches designed a solar chimney system for power production in high places and they evaluated the performance of that system (Tan and Shojaei 2019). They developed first a mathematical model depending on thermodynamic and meteorological cycle and then some codes on MATLAB software. The thermal performance of a system with 5-MW nominal power, which is located in Ottowa region in Canada, has been examined. A collector has been set up over a plain area on the hill of the mountain, and a natural chimney system has been designed there. Later, a small chimney and a turbine with vertical axes have been added (Bilgen and Rheault 2005). In 2007, Xingping *et al.* has developed a mathematical model in order to increase the performance of solar chimney power system through a simulation application (Xinping *et al.* 2007b). By means of this simulation what the power output will be like for differing solar light quantities, collector areas and chimney heights can be calculated. The air flux under the collector and the performance of the solar chimney can be evaluated by comparing other factors. In 2009, Zou created the theoretical mathematical modelling for optimum chimney height to obtain maximum power in solar chimney systems (Yabuz 2009, Zhou 2017).

The system built by Kulunk in Izmit has a chimney height of 2 m, and chimney diameter of 0.07

m and a collector area of 9 m^2 and it produces 0.14 W electricity (Kulunk 1985). Dai et al produces 110-190 kW electricity monthly through the solar chimney energy station with 200 m height, 10 m diameter and a collector area of 196.270 m^2 in the northwestern part of China (Liu *et al.* 2018). In their study where Siyang Hu *et al.* examined divergent chimneys' effect on the energy produced, they show that divergent chimneys are superior to cylindrical chimneys and that the bigger the divergence angle and the collector are, the more power the system produces (Hu *et al.* 2017). In their study, Zhou et al have proved that moisture, environmental temperature and the solar light are the effective parameters on solar chimney power systems (Zhou *et al.* 2017). Ayadi et al, in their study, stated that collector roof height in solar chimney systems had a significant importance and that as the height of the roof of the collector decreases, the power produced increases (Ayadi *et al.* 2018). In 1997, a prototype study was realized by Padki *et al.* within the context of a project supported by American Florida University in Florida region (Koyun 2006). As its chimney height, collector diameter, chimney entrance diameter and the chimney exit diameter values were 7.92 m, 9.15 m, 2.28 m and 0.61 m, respectively, it can be said it was an experimental system. Vieira et al has shown by fixing the ratio of collector height to the collector entrance height constant that the performance of the system changes when the proportion of the diameter of the collector to the height of the collector entrance and the proportion of the diameter of the collector to the entrance high of the collector entrance is changed (Vieira *et al.* 2017).

The aim of this study is to examine the solar chimney power plant prototype, which is one of the electrical energy production methods from solar energy, from various aspects and to analyze the suitability of the solar chimney power plant in Adıyaman conditions.

2. Design and modelling of solar chimney energy power plant

2.1 Solar chimney energy power plant structures simulation

There are three fundamental principles in Solar Chimney systems. These are as follows: greenhouse effect, chimney draught due to temperature difference and density and the kinetic energy. The system is made up of either a circular or a close-to-circular form greenhouse section and the chimney positioned right in the middle of this area. Air below the circular glass collector heats thanks to the sunlight coming to the surface of the collector. The warming air, because of the density difference with that of the cold air outside, moves towards the center of the collector. With the help of the chimney at the center of the collector, the draught of air gets faster and this air is thrown out through the open-top vertical chimney. Air that returning back to the chimney with an increased speed, causes the turbines to turn thanks to the turbine blades in the entrance section of the chimney, and so is electricity obtained, meanwhile. The turbine rpm is directly related to the incoming solar radiation. Chimney draws in air from underneath the collector, air comes in through the gaps at either side of the collector. Thus, a permanent operation is being provided (Koyun 2006, Yabuz 2009, Delikanlı and Yabuz 2011). Fig. 1 shows the basic operating principle of the solar chimney.

Though solar chimney systems work like a wind turbine, the problem, seen at wind turbines, that if there is no wind, then there is no energy doesn't see at solar chimney systems. Because, as long as there is any sunlight, the air in the greenhouse will get warmer and thus will move in the chimney. In addition, as the air draught is constant in the system, there is no need for the complex and expensive systems that are utilized to detect the orientation of the wind which we see at wind turbines. With a suitable collector area under the chimney and a suitable height of chimney, it is

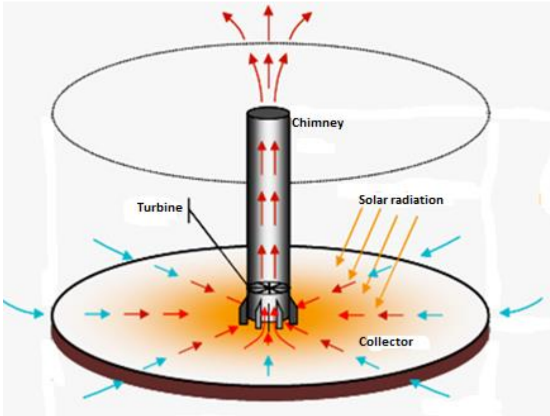

Fig. 1 The basic operating principle of the solar chimney (Schlaich 2005)

possible to produce 150-200 MW power.

2.2 Mathematical model

The fundamental parameters and their effect on power production and their relation are shown below. In order to calculate the power production quantity of a solar chimney, sun input, and the related efficacy of both the chimney and turbine are multiplied (Schlaich 2005, Bugutekin 2012a)

$$P = \dot{Q}_{\mathrm{solar}} \cdot \eta_{\mathrm{coll}} \cdot \eta_{\mathrm{sc}} \cdot \eta_{\mathrm{turbine}} = \dot{Q}_{\mathrm{solar}} \cdot \eta_{\mathrm{system}} \tag{1}$$

The solar energy coming into the solar chimney $\dot{Q}_{\mathrm{solar}}$ can be written as a product of global horizontal radiation G_h and the area of the collector A_{coll} (Schlaich 2005, Bugutekin 2012a)

$$\dot{Q}_{\mathrm{solar}} = G_h \cdot A_{\mathrm{coll}} \tag{2}$$

The chimney converts the heat flow produced by the collector into kinetic (convection flow) and potential energy (the pressure decreases in the turbine). Therefore, the density difference in the air occurring as a result of the temperature increase in the turbine acts as a thrusting force. The air heated at the bottom of the collector is released to the atmosphere from the top of the chimney and so the air flow gets a thrusting force. The pressure difference between the surrounding and the chimney (at the collector exit) Δp_{tot} is calculated in the following way (Schlaich 2005, Bugutekin 2012a)

$$\Delta p_{\mathrm{tot}} = g. \int_0^{H_t} (\rho_a . \rho_c) \, . dH \tag{3}$$

Thus, Δp_{tot} increases as the height of the chimney increases.

The pressure difference Δp_{tot} can be calculated from the sum of static and dynamic components by omitting losses resulting from friction (Schlaich 2005, Bugutekin 2012a)

$$\Delta p_{\mathrm{tot}} = \Delta p_s + \Delta p_d \tag{4}$$

Static pressure difference decreases in turbines but the dynamic component defines the kinetic energy of the air flow. When Δp_s=0, if total pressure difference and the flow volume of air are taken into account P_{tot} of the flow can be calculated through (Delikanlı and Yabuz 2011, Bugutekin 2012a)

$$P_{\mathrm{tot}} = \Delta p_{\mathrm{tot}} \cdot V_{\mathrm{chimney,max}} \cdot A_{\mathrm{coll}} \tag{5}$$

$$\eta_{\mathrm{sc}} = \frac{P_{\mathrm{tot}}}{Q} \tag{6}$$

The separation into static and dynamic components of the real pressure difference is dependent on the energy the turbine generates. The maximum flow rate $V_{\mathrm{chimney,max}}$ is obtained in a chimney without a turbine, and the whole pressure difference speeds the air and thus turns into kinetic energy (Delikanlı and Yabuz 2011, Bugutekin 2012a)

$$P_{\mathrm{tot}} = \frac{1}{2} m V_{\mathrm{chimney,max}}^2 \tag{7}$$

The velocity obtained at free transfer by using Boussinesq equation is (Delikanlı ve Yabuz 2011, Bugutekin 2012)

$$V_{\mathrm{chimney,max}} = \sqrt{2.g.H_t.\frac{\Delta T}{T_0}} \tag{8}$$

By combining the equations above the efficacy of the chimney can be stated as follows

$$\eta_{\mathrm{sc}} = \frac{\mathrm{g.H}}{c_p.\mathrm{T_0}} \tag{9}$$

And the efficacy of the collector

$$\eta_{\mathrm{coll}} = \frac{\dot{Q}}{A_{\mathrm{coll}}.\mathrm{G}} \tag{10}$$

where *Q* is the power at the exit of the collector, A_{coll} is the surface area of the collector, and *G* is the total solar radiation coming to the surface of the collector.

$$\dot{Q} = \dot{m}.c_p.\Delta T \tag{11}$$

$$\dot{m} = \rho_{\mathrm{coll}}.V_{\mathrm{coll}}.A_{\mathrm{coll}}\ (\rho_{\mathrm{coll}} = T_0 + \Delta T) \tag{12}$$

So, the collector efficiency equation is obtained as follows.

$$\eta_{\mathrm{coll}} = \frac{\rho_c.\mathrm{V}_c.\mathrm{A}_c.c_p.\Delta\mathrm{T}}{A_{\mathrm{coll}}.\mathrm{G}} \tag{13}$$

and the heat balance in the collector is formulated as

$$Q = \propto.A_{coll}.G - \beta.\Delta T.A_{coll} \tag{14}$$

when this equation is combined with Eq. (10) a second equation for the collector efficacy is obtained

$$Q\eta_{coll} = \propto - \frac{\beta.\Delta T}{G} \tag{15}$$

if Eqs. (13) and (15) are combined and organized to get V_c, we get

$$V_c = \frac{\propto.A_{coll}.G - \beta.\Delta T.A_{coll}}{\rho_c.A_c.c_p.\Delta T} \tag{16}$$

if P_{tot} is picked out from Eq. (6), and if *Q* is written explicitly, we get

$$P_{\mathrm{tot}} = \frac{\mathrm{g.H}}{c_p.\mathrm{T_0}} \rho_c.c_p.V_c.\Delta T.A_c \tag{17}$$

if, moreover, the equation $\dot{V} = V_t . A_t$ for air flow of volume is written, Eq. (5) becomes

$$P_{\text{turbine}} = \dot{V} . \Delta p_{\text{turbine}} \tag{18}$$

This equation resembles to the *P=U.I* equation of electrical systems, in which power is obtained by the multiplication of voltage and current. In this equation I corresponds to volume air flow while U corresponds to the term $\Delta p_{\text{turbine}}$. And, when $\Delta p_{\text{turbine}}$ is zero, the power obtained is also zero.

On the other hand, when $\Delta p_{\text{turbine}}$=$\Delta p_{\text{tot}}$, a case of idle-running occurs. Between these two values P_{turbine} reaches to its maximum value. In that case the velocity of air is stated as follows (Koyun 2006)

$$V_{\text{t,max}} = \sqrt{\frac{2}{3} . \frac{\Delta p_{\text{turbine}}}{\rho_t}} \tag{19}$$

Therefore, to get the maximum power, 2/3 of the whole pressure difference should be lowered in the turbine. So, the mechanical power to be obtained from the turbine becomes (Koyun 2006)

$$P_{\text{mec}} = \frac{2}{3} \eta_{\text{sc}} . \eta_{\text{coll}} . A_{\text{coll}} . G \tag{20}$$

When the efficacy terms are written in the equation, we get

$$P_{\text{mec}} = \frac{2}{3} \frac{g \cdot H}{c_p \cdot T_0} . \left(\propto - \beta . \frac{\Delta T}{G} \right) . A_{\text{coll}} . G \tag{21}$$

The mechanical power obtained in this way can be multiplied with the efficacy of the turbine and thus the electrical power that will be obtained from the turbine can be calculated as (Koyun 2006)

$$P_{\text{elc}} = P_{\text{mec}} \cdot \eta_{\text{turbine}} \tag{22}$$

2.3 Construction of the application system

In order for the research to be applied an open area, which gets constant sunlight during the day, with the coordinates of 38° 11° - 37° 25° north latitude and 39° 14° - 37° 31° east longitude with an altitude of 669 m was chosen in the campus of Adıyaman University in Turkey's Southeastern Anatolian Region in March 2009, and the prototype of the solar chimney powerhouse was established there in June 2010 within the scope of the project supported by the Adıyaman University Scientific Research Projects Unit. Moreover, during the manufacturing of the prototype, the support of TPAO Adıyaman Region Directorate was acquired.

The outline of the solar chimney system established in the campus of Adıyaman University was given in Fig. 2 and the physical parameters of the system were given in Table 1.

2.3.1 Preparation of the groundwork

As a ground floor is needed to absorb the solar radiation during the daytime and store it in the form of heat in order to continue the performance of the solar chimney during the night, the special ground floor was prepared, whose schematic diagram and production details are shown with photos (see Fig. 3) (Bugutekin 2012a).

Firstly, by means of covering the floor of the hole, 27 m in diameter and 0.5 m in depth, with aluminium foil of 0.05 m thickness, the heat stored during the daytime was prevented from transferring into the soil [36]. Then, a special floor was prepared by spreading pebbles of 0.10 m thickness over the glasswool with aluminium foil, then a layer of 0.05 m fine sand, and a layer of

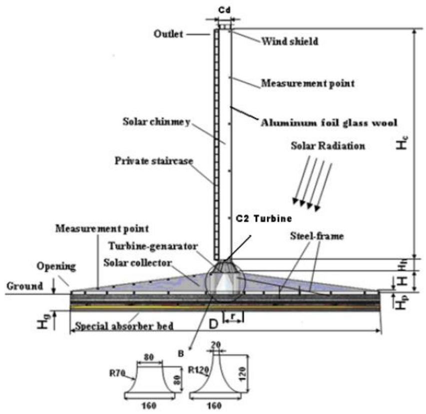

Fig. 2 Schematic diagram of solar chimney power plant (Bugutekin 2011)

Table 1 Main parameters of the solar chimney power plant

Parameter	Symbol	Value (m)
Collector diameter	D	27
Funnel radius	R	1.1
Height from collector outlet to ground level	H	1.35
Size of the opening at the periphery	H_p	0.05
Chimney diameter	C_d	0.8
Chimney height	H	15
Special absorber bed thickness	H_g	0.5
Funnel height	H_h	0.8
Base width and height of the lower funnel (respectively)	B	1.6-0.8
Height of turbine from ground	C_2	2.15

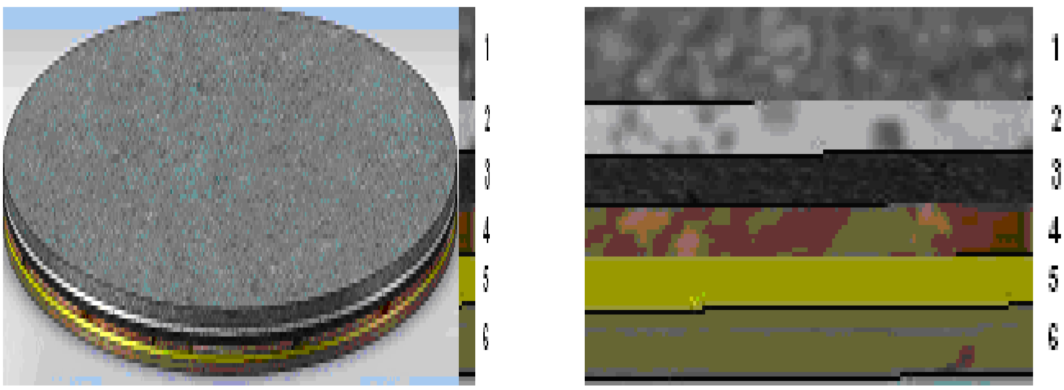

Fig. 3 Ground (1. Asphalt, 2. Glass, 3. Thick sand, 4. Gravel, 5. Aluminum foil with glass wool, 6. Ground floor)

0.05 m (15 tones) glass particles, and at the top a layer of 0.25 m asphalt was spread (Bugutekin 2012a).

Fig. 4 Picture of solar chimney power plant

2.3.2 Preparation of the chimney

In the construction of the chimney, which is one of the most important parts of solar chimney system, at first the main funnel and the internal funnel, on which turbine blade and the turbine will be assembled, were produced from a metal sheet with a thickness of 0.007 m in order to enable a straight passage of the air directed from the bottom of the collector to the chimney (Fig. 2). Later, straps of 0.2 m in thickness were assembled onto lower and upper parts of the main funnel in order to maintain the connection of the main funnel with its carrying feet and with the chimney. A cage structure was formed before the spread of the ground in order to fix the main funnel on the soil safely. Finally, a chimney of 0.8 m in diameter and 15 m in height produced from a metal sheet of 0.007 m thickness was put onto the main funnel. The circumference of the chimney was covered with 0.05 m glasswool with aluminium foil in order to keep the inner part of the chimney at a low temperature.

2.3.3 Preparation of the collector

A collector was manufactured in order to prepare the sera environment, which transforms the solar radiation to heat in the solar chimney system. Collector carrying parts were manufactured from metal square or rectangular profiles of dimensions of 0.04×0.04 m, 0.04×0.08 m and 0.02×0.02 m to withstand powerful winds. Metal profiles of the collector were isolated in order not to let them absorb the ground heat. The Solar Collector was manufactured with a slope of 6^0 in accordance with the solar slope of the city, Adıyaman. The upper part of the collector was covered with glass of 0.004m in four stages in view of the models designed. The gaps between glass and profiles were filled with silicon so as to maintain flexibility, impermeability, and strength. Edges of the collector were closed with a bladed mechanism that can be adapted according to the heights, with a thickness of 0.05-0.35 m in order to make the air inflow possible. And, in order to advance the durability of the solar chimney, the chimney was fixed to the ground from four different points with steel ropes (see Fig. 4) (Bugutekin 2011).

2.3.4 Wings and the turbine

In our study over the measurements done without a turbine, it has been decided that it would be suitable to use a DC wind turbine specially designed with a vertical axis at the entrance of the chimney. While choosing the profiles for wings standards determined by NACA (National Advisory

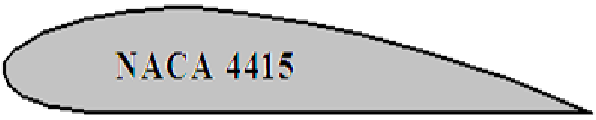

Fig. 5 NACA Blade Profile Model

Committe for Aeronautics) were taken into consideration and the letters and numbers used on blades were defined in accordance with NACA standarts (see Fig. 5).

Specially designed NACA 4415 wing profile was used in the research. 44 stands for the wing profile and 15 denotes the percentage of airfoil relative thickness (Aras 2010).

The most important factors affecting the performance of the wind turbine are the speed of the wind and swept area, which depends on the span of the turbine blades. Wind power will increase in direct proportion to the cube of the speed and the area of the wheel as the wind speed increases. The equation giving the maximum energy is as follows.

Kinetic energy in the wind is

$$T = \frac{1}{2} . \rho . A . V_r^3 \tag{23}$$

But, the winglets exploit from a certain part of this energy

$$P_{\text{max}} = C_{\text{pBetz}} . \frac{8}{27} . \rho . A . V_r^3 \tag{24}$$

From these two equations

$$C_{\text{pBetz}} = \frac{P_{\text{max}}}{T} = \frac{16}{27} = 0{,}5926 \tag{25}$$

C_{pBetz} : Betz Coefficient (is the power coefficient and its maximum value is %59.26. This value is called as Lanchester-Betz limit. This limit shows that a wind turbine can have an efficacy of %59.26 as a maximum) (Aras 2010).

As a power production of low-scale is going to be applied, DC dynamos have been chosen to use instead of those used big-scale wind turbines. Advantages of the DC turbines, which will be used for power production, are its practicality, easy changeability, the little revolving resistance exposed to the axis from the wings, and easy storage to batteries.

For the solar chimney system on Adıyaman University campus, turbines with 0.8 m and 1.2 m wing diameters have been manufactured specially (see Figs. 6 and 7) (İçel 2012).

After the calculations done on the system about like the air flow rate and the area for the generators' setting, DC generators specially designed for that system have been produced (see Fig. 8). Technical properties of the generators used in the systems are given on Table 2.

3. Measurements and results

Measurements of temperature distribution in the solar chimney system can be seen in Fig. 9.

Air temperature changes and the speed of the air at the turbine entrance and exit of the solar chimney and the turbine cycling measurements are shown on Fig. 10.

As the measurements done daily from 22nd July 2010 to 31st July 2010 were greatly parallel

Fig. 6 Turbines used in the solar chimney power plant (r=0.4 m)

Fig. 7 Turbines used in the solar chimney power plant (r=0.4 m)

Fig. 8 The generator in the solar chimney power plants

Table 2 Main parameters of the generator in the solar chimney power plants

Size (mm)	Weight (kg)	Frequency (Hz)	Power (W)	Voltage (V)	Current (A)	Rotation (RPM)
85×200×82	3,8	40-80	100 (Max)	35-70 (DC)	4	600-1200

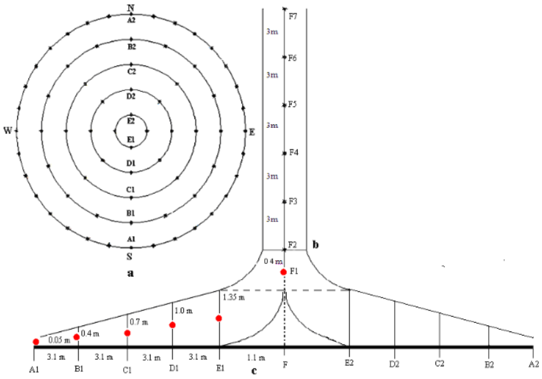

Fig. 9 Air temperature measurement points in the solar chimney system (a) Measure points on ground (asphalt), (b) Measure points from the center of the chimney and their heights and (c) Measure points and heights under the collector (Bugutekin 2012b, İçel 2012)

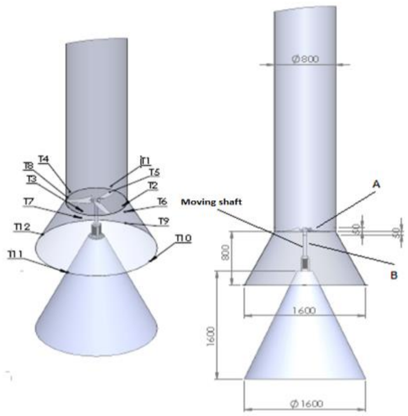

Fig. 10 Air temperature changes and the speed of the air at the turbine entrance and exit of the solar chimney and the turbine cycling measurements (Turbine position A: r=0.4 m, B: r=0.6 m) (Bugutekin 2012b, İçel 2012)

before the mounting of the turbine of the solar chimney system, the measurements obtained on 26th July of 2010 were utilized.

The temperature and air velocity measurement values of the collector, floor and inside the chimney on Figs. 11, 12 and 13 were taken at 13:00, when the solar radiation is high in Adıyaman.

In Fig. 11, it is seen that the ground perfectly absorbs the solar radiation and so gets warmer and by transmitting some of this heat to the air flow coming from the entrance of the collector and so goes on towards the chimney. F1 point at the center of the collector shows the highest temperature while A2 point which is on the north and at the entrance point of the collector shows the lowest temperature value.

For the given chimney at the predefined points in the chimney through the measured values, in Fig. 9, it is seen that as the temperature below the collector increases the temperatures at points F1 and F2 climbs to maximums, and in Fig. 12, it is seen that the temperature values through the points F3 to F7 decreases with altitude. This situation is connected to two reasons: the first is that warming air loses its temperature as it goes higher, and the second is because the outer part of the chimney is isolated.

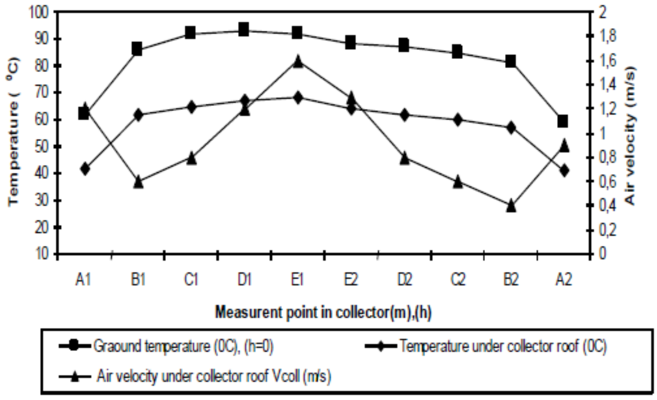

Fig. 11 Ground and collector temperature distribution and air velocity change at predefined spots and heights of the solar chimney system (at 13:00 when outside temperature, air velocity and the measured solar radiation were 41 °C, 1.3 m/s, 830 W/m^2, respectively)

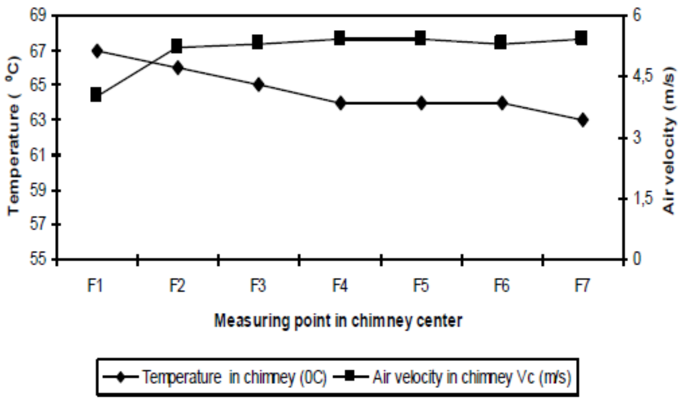

Fig. 12 Temperature distribution and air velocity change of the air at the center of the chimney at predefined spots and heights of the solar chimney system (at 13:00 when outside temperature, air velocity and the measured solar radiation were 41 °C, 1.3 m/s, 830 W/m^2, respectively)

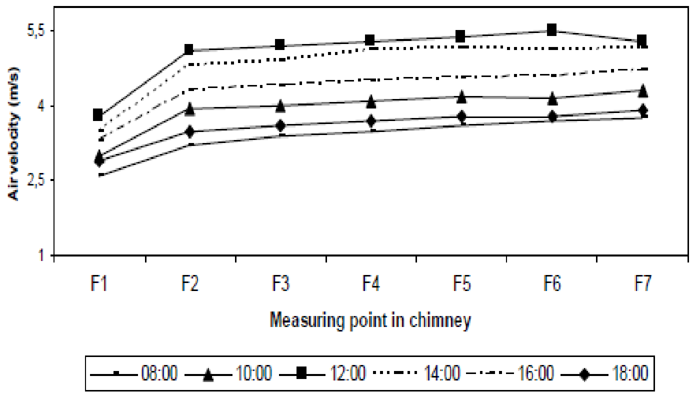

Fig. 13 Hourly air velocity(m/s) changes at predefined points and heights in chimney of the Solar Chimney System

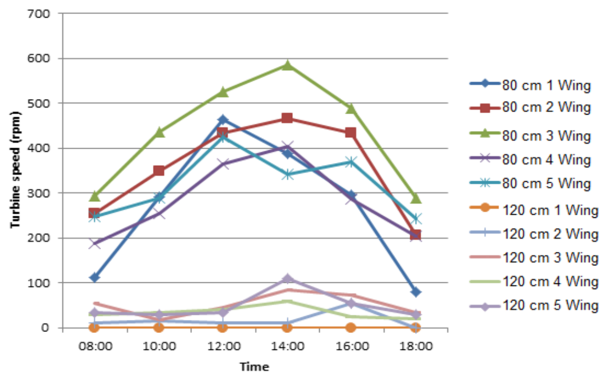

Fig. 14 The revolutions of the turbine speed et the different diameters in the solar chimney system (27.07.2011)

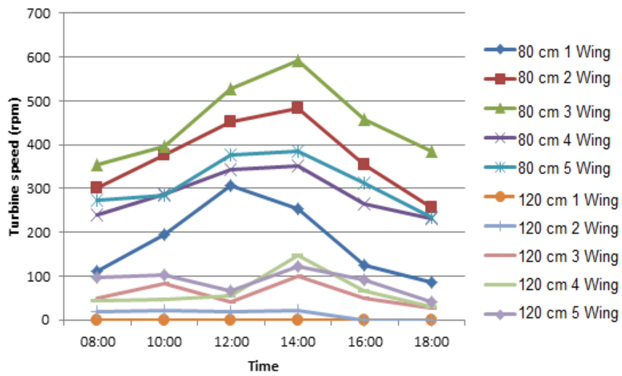

Fig. 15 The revolutions of the turbine speed at the different diameters in the solar chimney system (29.07.2011)

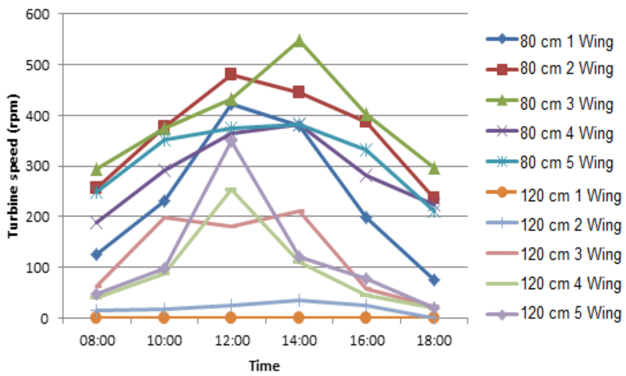

Fig. 16 The revolutions of the turbine speed at the different diameters in the solar chimney system (31.07.2011)

When Fig. 13 was examined, it was observed that while the speed of the air in the chimney at point F1 (1,2 m) is low because of the big funnel diameter of the lower part, that of the point F2, where the chimney abruptly narrows, increases rapidly. However, the air flow through points F3-F7 was observed to increase very little and the reason of this were seen to be the smoothness of the inner surface of the chimney and thus a minimum friction and therefore thanks to the height of the chimney a natural absorption is observed.

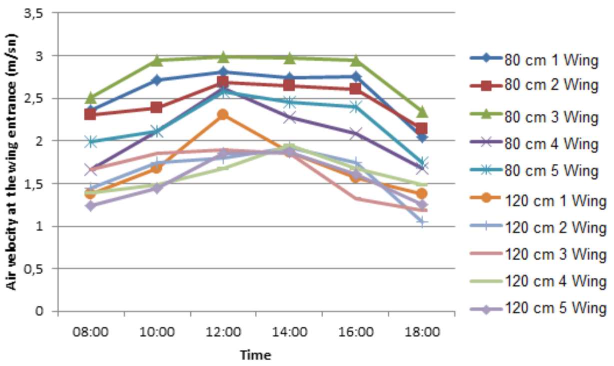

Fig. 17 The revolutions air velocity at the wing entrance of the turbine at the different diameters in the solar chimney system (27.07.2011)

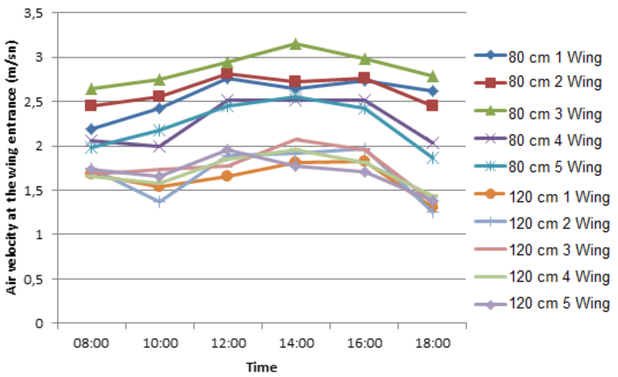

Fig. 18 The revolutions air velocity at the wing entrance of the turbine at the different diameters in the solar chimney system (29.07.2011)

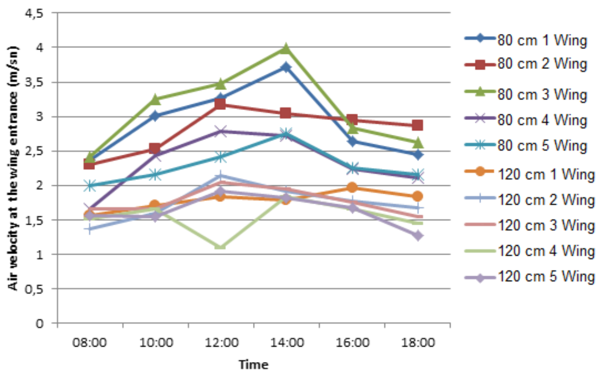

Fig. 19 The revolutions air velocity at the wing entrance of the turbine at the different diameters in the solar chimney system (31.07.2011)

Measurements done after the mounting of the turbine in the solar chimney system, were done daily on 27th, 29th and 31st July, 2011 and the data obtained from those were used.

When turbines of different diameters were montaged, the turbine with a diameter of 0.8 m was assembled to the point A in Fig.10 and the measurements were done for the point F2. The turbine with a diameter of 1.2 m was assembled to the point B in Fig.10 and the measurements were done for the point F1.

When Figs. 14, 15 and 16, which includes the measurements done on different days, are examined, it is seen that cycle numbers of the turbine with a diameter of 0.8 m were very high than that of the turbines with a diameter of 1.2 m. Cycling number and the air velocity at the entrance of the turbine change in a parallel way in wind turbines.

At the measurements done after the mounting of turbines, it was detected that air velocity rate of the turbine with a diameter of 0.8 m were higher than that of the turbines with a diameter of 1.2 m (Figs. 17, 18 and 19).

When rotational frequency of the turbine and air velocity speed at the wing entrance of the turbine are taken into consideration, the most suitable wing diameter for the established system was understood to be 0.8 m.

The system established in this study is larger than the other prototype systems in the literature in terms of chimney height, collector diameter and chimney diameter parameters (Ayadi *et al.* 2018, Koyun 2006, Kulunk 1985, Vieira *et al.* 2017). In addition, different turbine blade geometries have been evaluated and the most efficient blade geometry was determined.

3.1 Limitations

The following situations constitute the limitations of the study due to the limitations of financial resources.

- A model with a larger chimney height and diameter could have been constructed.
- Turbine blades could also be manufactured with different inclination angles.
- The effect of the ground materials on the heat storage could have been investigated.

4. Conclusions

At the solar chimney system established at the campus of Adıyaman University, according to solar radiation and environmental temperature and air speed conditions of Adıyaman, through the measurements done on certain points of the chimney, the collector and the turbine, these results have been concluded.

- The specially prepared ground in the solar chimney system reaches to a maximum temperature and the heat storage property of the ground is an important parameter in view of both the heating of the air flowing from the collector to the chimney and the continuation of the system's running at night,
- The temperature beneath the collector increases as it goes towards the chimney and it decreases through the chimney as it climbs up,
- Air flow is higher, even if it is very little, at the entrance of the collector, and it sees its minimum beneath the collector and increases its speed rapidly at the entrance of the chimney in the solar chimney system,
- It is suitable for energy production with low-level solar chimney systems to utilize a turbine system with a vertical axe at the entrance of the chimney in order to get the maximum performance,

- It is determined that in this kind of solar chimney systems, best results can be achieved with a turbine of 0.8 m diameter.

In conclusion, the following can be said that solar chimney systems are an alternative for energy production in the conditions of Adıyaman, and the prototype can be developed and a solar chimney electricity power plant can be installed, and as two of the most important factors in solar chimney systems are chimney height and the diameter of the collector, by taking the fact that Adıyaman is an earthquake area of second order, a collector construction over a large area can be a better solution in the region.

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References

Aras, M.M. (2010), "Design, manufacture and performance testing of a small wind turbine", Graduation Project, Başkent University, Ankara, Türkiye.

Ayadi, A., Bouabidi, A., Driss Z. and Abid, M.S. (2018), "Experimental and numerical analysis of the collector roof height effect on the solar chimney performance", *Renewab. Energy*, **115**, 649-662. https://doi.org/10.1016/j.renene.2017.08.099.

Bernardes, M.A.S. (2003), "Symmetric sink flow and heat transfer between two parallel disks", *ASME Heat Transfer Summer Conference*, Las Vegas, Nevada, USA, July.

Bilgen, E. and Rheault, J. (2005), "Solar chimney power plants for high latitudes", *Solar Energy*, **79**(5), 449-458. https://doi.org/10.1016/j.solener.2005.01.003.

Bugutekin, A. (2011), "Effect of the collector diameter on solar chimney power plants", *Energy Educ. Sci. Technol. Part A: Energy Sci. Res.*, **27**(1), 155-168.

Bugutekin, A. (2012a), "An experimental investigation of the effect of periphery height and ground temperature changes on the solar chimney system", *J. Therm. Sci. Technol.*, **32**(1), 51-58.

Bugutekin, A. (2012b), "Experimental study of temperature field in a solar chimney plant in Adiyaman", *J. Therm. Sci. Technol.*, **32**(2), 73-80.

Chamber Report (2022), "Turkey's energy outlook", MMO/731; TMMOB Chamber of Mechanical Engineers, Ankara, Türkiye.

Delikanlı, K. and Yabuz, Z.R. (2011), "Investigation of efficiency-enhancing methods in the solar chimney prototype", *C.B.U. Soma Vocat. School Tech. Sci. J.*, **1**(15), 36-54.

Gannon, J.A. (2002), "Solar chimney turbine performance", Ph.D. Dissertation, Stellenbosch University, Stellenbosch, South Africa.

Hu, S., Leung, D.Y.C. and Chen, M.Z.Q. (2017), "Effect of divergent chimneys on the performance of a solar chimney power plant", *Energy Procedia*, **105**, 7-13. https://doi.org/10.1016/j.egypro.2017.03.273.

İçel, Y. (2012), "Investigation of efficiency of production electricty in solar chimney power plants using different wing models", MSc Dissertation, İnönü University, Malatya, Türkiye.

Koyun, A. (2006), "Investigation of energy production by the solar chimney", Ph.D. Dissertation, Süleyman Demirel University, Isparta, Türkiye.

Kulunk, H. (1985), "A prototype solar convection chimney operated under Izmit conditions", *Proceedings of 7th Miami International Conference on Alternative Energy Sources*, Miami Beach, FL, USA, December.

Liu, Q., Cao, F., Liu, Y., Zhu, T. and Liu, D. (2018), "Design and simulation of a solar chimney PV/T power

plant in Northwest China", *Int. J. Photoenergy*, **2018**, 1-12. https://doi.org/10.1155/2018/1478695.
Mekhail, T., Rekaby, A., Fathy, M., Bassily, M. and Harte, R. (2017), "Experimental and theoretical performance of mini solar chimney power plant", *J. Clean Energy Technol.*, **5**(4), 294-298. https://doi.org/10.18178/jocet.2017.5.4.386.
Mirza, Z.T. and Abedi, M. (2020), "Introduction of an environmentally optimized energy scenario for the future of Indian power industry", *Adv. Energy Res.*, **7**(2), 101-121. http://doi.org/10.12989/eri.2020.7.2.101.
Papadopoulos, D.N., Antonopoulos, C.N. and Papadakis, V.G. (2022), "Environmental assessment of a BIPV system", *Adv. Energy Res.*, **8**(1), 1-19. http://doi.org/10.12989/eri.2022.8.1.001.
Quaschning, V. (2005), *Understanding Renewable Energy Systems*, Earthscan, London, UK.
Schlaich, J., Bergermann, R., Schiel, W. and Weinrebe, G. (2005), "Design of commercial solar updraft tower systems - utilization of solar induced convective flows for power generation", *J. Sol. Energy Eng.*, **127**(1), 117-124. https://doi.org/10.1115/1.1823493.
Tan, F. and Shojaei, S. (2019), "Past to present: Solar chimney power technologies", *El-Cezeri J. Sci. Eng.*, **6**(1), 220-235. https://doi.org/10.31202/ecjse.474363.
Vieria, R.S., Petry, A.P., Rocha, L.A.O., Isoldi, L.A. and dos Santos, E.D. (2017), "Numerical evaluation of a solar chimney geometry for different ground temperatures by means of constructal design", *Renewab. Energy*, **109**, 222-234. https://doi.org/10.1016/j.renene.2017.03.007.
Xinping, Z., Jiakuan, Y., Xiao, B. and Guoxiang H. (2007b), "Simulation of a pilot solar chimney thermal power generating equipment", *Renewab. Energy*, **32**(10), 1637-1644. https://doi.org/10.1016/j.renene.2006.07.008.
Xinping, Z., Yang, J., Xiao, B. and Hou, G. (2007a), "Experimental study of temperature field in a solar chimney power setup", *Appl. Therm. Eng.*, **27**(11-12), 2044-2050. http://dx.doi.org/10.1016/j.applthermaleng.2006.12.007.
Yabuz, Z.R. (2009), "The study on the constructional improvements and the research of methods to increase the performance of the solar chimney", MSc Dissertation, Süleyman Demirel University, Isparta, Türkiye.
Zhou, X., Xu, Y. and Zhang, F. (2017), "Evaluation of effect of diurnal ambient temperature range on solar chimney power plant performance", *Int. J. Heat Mass Transf.*, **115**, 398-405. https://doi.org/10.1016/j.ijheatmasstransfer.2017.07.051.

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Nomenclatures

A_{coll}: Solar collector area (m^2)
G: Solar irradiance (W/m^2)
H_{sc}: Solar chimney height (m)
P_{tot}: Useful energy contained in the airflow (kW)
η_{coll}: Solar collector efficiency
η_{sc}: Solar chimney efficiency
$\eta_{turbine}$: Turbine efficiency
P_{elc}: Electrical power (W)
P_{mec}: Mechanical power (W)
ΔP_{tot}: Pressure difference produced between chimney base and the surroundings (Pa)