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Past to Present: Solar Chimney Power Technologies

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Abstract: This study introduces the solar chimney power technology, which is a solar thermal energy system. One of the renewable energy resources, this system is an energy transformation system in which solar energy and wind energy are used together. In this system, the air that is heated with solar energy ensures the production of electric energy by moving upwards with the suction effect of the chimney and rotating the turbine that is placed inside the chimney. In this review, the main principles and characteristics of this system are discussed and the developments on the experimental and theoretical investigations carried out with regard to the solar chimneys around the world especially in recent years are shared with the readers. With the study, it is aimed to provide up-to-date information to readers who are interested in this subject.

Keywords: Solar chimney, Renewable energy, Review.

Geçmişten Günümüze: Güneş Bacası Güç Teknolojileri

Öz: Bu çalışma, bir güneş termal enerji sistemi olan güneş bacası güç teknolojisini tanıtmaktadır. Yenilenebilir enerji kaynaklarından biri olan bu sistem, güneş enerjisi ve rüzgar enerjisinin birlikte kullanıldığı bir enerji dönüşüm sistemidir. Bu sistemde, güneş enerjisi ile ısıtılan hava, baca emme etkisi ile yukarı doğru hareket ederek ve baca içerisine yerleştirilen türbini döndürerek elektrik enerjisinin üretimini sağlar. Bu derlemede, bu sistemin temel ilkeleri ve özellikleri tartışılmakta ve özellikle son yıllarda dünyanın çeşitli yerlerinde güneş bacaları ile ilgili yapılan deneysel ve teorik incelemelerdeki gelişmeler okuyucularla paylaşılmaktadır. Çalışma ile, bu konuyla ilgilenen okuyuculara güncel bilgi sağlanması amaçlanmıştır.

Anahtar kelimeler: Güneş bacası; Yenilenebilir enerji; Derleme

1. Introduction

Solar chimney is a renewable energy transformation system which consists of mainly three components. Solar energy heats the air under a large collector. The heated air moves towards the centre of the collector under the suction effect of a chimney and activates the turbine that is placed inside the chimney (Fig. 1) [1]. The first study about this system was in 1500s, Leonardo Da Vinci made sketches of a solar tower [2]. In 1903, Spanish engineer Isodoro Cabanyes first put forth the idea of using a solar chimney to produce electricity [3]. The first patent application was made in 1975 by Robert E. Lucier. In 1978, the modelling of a concept solar chimney was designed by J. Schlaich [4]. This facility in Manzanares region of Spain had a 122 m of collector radius, 194,6 m of chimney height and 10 m of chimney diameter.

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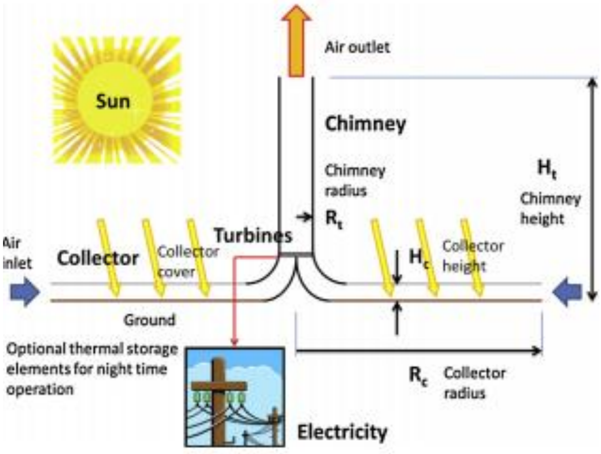


Figure 1. Solar chimney power system [1]

W. Haaf published the results of Manzanares pilot study first in 1984 [5] and then he published a book in which the main principles of solar chimneys are accounted first in 1995 and the second in 2004. R.J. Krisst constructed a solar chimney system of 10 W power, 6 m collector diameter and 10 m chimney height in 1983 [6]. Many studies and projects have been performed in the following years. Table 1. summarizes chimney power plants around the world [7]

Table 1. Some solar chimney power plants around the world [7]

Region	Solar Chimney Power Plant			
	Collector radius	**Chimney height (m)**	**Chimney Radius (m)**	**Power output**
Manzanares,Spain	122	194.6	5.08	36-41 kW
Yinchuan, China	250	200	5	110-190 kW
Mediterranean	625	550	41	2.8-6.2MW
Arabian Gulf R.	1000	500	50	>8 MW
Adrar, Algeria	250	200	5	140-200 kW
Qinghai, Tibet	2825	1000	40	372-829 TJ/year
Kerman, Iran	40	60	1.5	4.035 kW
Iran	122	194.6	5.08	175-265 MWh year

2. Experimental Investigations

In the literature, many experimental studies have been reported on the feasibility and performance of solar chimneys with various geometries. In their study, Ghorbani *et al* present an improved concept design with the aim of increasing the thermal efficiency of the Rankine cycle of a typical steam power plant by coupling a solar chimney and a dry cooling tower [8]. A numerical finite volume code was employed for a dry cooling tower with a base diameter and a chimney height of 250 and 200 m, respectively. Changing the hybrid tower geometrical parameters, power ranging from 360 kW to more than 4.4 MW was captured by the wind turbine.

In the study of Shahreza and Imani, an air tank was placed down the system in order to increase the absorption of the solar radiation reflected by the intensifiers. The results of the experiment showed that using the intensifiers led to an increase in the speed value within the chimney, and thus, more power was produced. The maximum speed achieved was 5.12 m/s. And this was noteworthy considering the small size of the SC structure [9].

Ghalamchi & Kasaeian designed a solar chimney pilot power plant with a 3 m collector diameter and 2 m chimney height. The temperature difference between the temperature at the chimney inlet and within the ambient reached up to 26.3 ◦C. The report demonstrates that a reduction in the inlet size has a positive effect on the power production performance of the solar chimney. While the entrance speed of the collector was nearly zero, a maximum air speed of 1.3 m/s was recorded inside the chimney [10]. Energy and exergy analyses of the airflow inside a solar chimney are presented in the paper of Maia *et al*. The results demonstrated that the exergy losses were lower and the efficiency was higher for the lowest ambient temperature that was used as the dead state temperature, by comparison with the instantaneous ambient temperature [11].

Zuo *et al* constructed a small-scale experimental device for solar chimneys combined with sea water desalination. The results of their experiment show that the integrated system can achieve a multi-targeted production such as power and freshwater, synchronously. The main period of the distilled water output is when the solar irradiance is absent; while the minimum output occurs during a time of strong radiance [12].

Kasaeian *et al* measured in their study; the temperatures and air velocities after designing and constructing a solar chimney pilot power plant with a collector of 10 m diameter and chimney height of 12 m. The temperature difference between the collector exit and the ambient reached up to 25◦C. While the velocity at the collector inlet was zero; the maximum air velocity of 3 m/s was recorded inside the chimney [13].

In an experimental system using electrode layouts, it has been observed that performance is increased 28% due to the electrohydrodynamic system used [14]. Hussain H. *et al*, in the present paper have investigated the impact of the inlet shape of the solar collector on the solar chimney performance experimentally and numerically [15].

Bouabidi *et al*, have studied on the effect of the chimney conformation on the solar chimney power plant performance. They focused on studying the solar chimney power plants with: standard, divergent, convergent and opposing chimney. The results show that the chimney form affects the air velocity behaviour [16].

Fadaei *et al*, through an experiment have studied the impact of latent heat storage (LHS) on a solar chimney pilot as regards two kinds of experiments including with and without phase change material (PCM) and the parameters like these: temperature and velocity. The results showed that the maximum absorber surface temperature for the solar chimney with phase change material and the conventional solar chimney are 72 °C and 69 °C [17].

3. Theoretical and Numerical Investigations

Theoretical and numerical investigations and mathematical modelling of solar chimney were also performed by the researchers. Pasumarthi and Sherif developed a mathematical model in order to examine the effects of some parameters on the power output. Furthermore, they investigated three different types of collector [18]. Bernardes et al. developed comprehensive, analytical and numerical models for the solar chimney. In their model, various environmental conditions were investigated, the output power in solar chimney system was calculated and the system was sized [19].

Backström and Fluri determined the optimum difference of pressure for the flow intensity. By using the collector model developed by Schlaich, they indicated that a maximum streaming flow intensity by 2/3 of the pressure difference may occur [20]. Sakonidou et al developed a mathematical model for analyzing the natural air flow created within the solar chimney. The model developed also foresees the density and heat of the air in the chimney, and the temperature of the heat absorbed by the absorber surface. The results were verified with experimental studies by prototyping the theoretical model developed [21]. Ming et al. conducted a numerical simulation in order to be able to analyze the heat transfer a solar chimney system created with an energy absorbing layer and the air flow in the chimney. The studies carried out shows that although the enthalpy rate first dropped, later the heat increased with the rise of the radiation from 200 W/m2 to 800 W/m2. Furthermore, the static pressure drops with the increase of the speed and radiation [22].

Tingzhen et al. carried out a numerical study examining the prototype model in Spain for a system combined with a turbine. In this system, separate mathematical models were established for the collector, chimney and turbine. The mathematical model results were analyzed for the three-wing turbine. The study also introduces a system simulation at MW level for the five-wing turbines [23]. Fluri and Backström proposed flow regulator units in order to reduce the aerodynamic losses occurring during the flow. They simulated turbines with single vertical axis, multiple vertical axis or multiple horizontal axis in order for the chimney performance [24]. Petela carried out an exergy work with theoretical energy balance on the solar chimney. In the study, it was shown that the 36.81 MW solar radiation energy turns into 32.41 MW solar radiation energy, and the other part is distributed to the solar chimney elements [25].

Maia et al investigated the air flow in the solar chimney in an instable state analytically and numerically. The analyses show that the chimney height and chimney diameter values are the most important parameters for the physical results in chimney design [26]. In a study carried out by Zhou et al, the optimum chimney height values of the system are mathematically modelled in obtaining the maximum power for solar chimney systems [27]. Bernardes et al compared the methods in which the heat flow used in collectors are calculated and their effects on the performance of the solar chimney [28].

Fluri et al compared the cost analysis models in the literature and saw that realistic values were not obtained. For this reason, they developed a new cost model on a solar chimney physical model they chose and compared in with other models [29]. Zhou et al numerically simulated the rise in the chimney of the mutually streaming air entering the solar chimney. In this analysis they conducted, the static pressure, temperature, density and the relative humidity in the flow, which are parameters affecting the performance were simulated on the opposite plane geometry [30].

In order to improve effectiveness of the solar chimneys, some researches were carried out [31]. According to Zou *et al*, the hybrid cooling-tower-solar-chimney system (HCTSC), which integrates solar chimney with natural draft dry cooling tower, produces electricity while at the same time dissipating waste heat for the coupled geothermal power plant. Results demonstrate that the HCTSC system can achieve over 20 times of increase in the power output of turbine, when compared to the traditional solar chimney with similar geometric dimensions [32].

In the work conducted by Zandian and Ashjaee, a dry cooling tower and a solar chimney design are recombined to expand the thermal effectiveness of a steam Rankine cycle. The rejected warmth from the condenser into the dry cooling tower supplemented by the solar radiation gained through its transparent cover are the sources of wind energy generation that is caught by a wind turbine which is situated toward the start of the chimney. The outcomes demonstrate a maximum of 0.37 percent increment in the thermal effectiveness of a 250 MW fossil fuel power plant unit; which demonstrates that this design is a critical change in effectiveness of thermal power plants, by catching the heat that is scattered from dry cooling towers [33].

Naraghi and Blanchard tested the model’s performances for various parameters of solar chimney that influence the thermal mass of the absorbing plate. They discretized energy balance equations for three components of solar chimneys, these being absorbing plate, cover glass and air-gap, with reference to time using an implicit finite difference model. It was found out that a solar chimney with a relatively large thermal-mass produces a good airflow at night and early in the morning when solar irradiance is absent. An absorbing plate with a high thermal mass leads to smaller variations in the airflow rate [34].

Guo *et al* developed a comprehensive theoretical model considering the hourly variation of solar radiation for the purpose of obtaining a more accurate prediction of the annual performance of solar chimney power plants. The influences of the radius of the collector and the chimney on the power output of the SCPP were analyzed; and the results showed that there is a limitation on the maximum collector radius for the maximum attainable power output of the SCPP. Then the researchers put forward four designs of 100 MW SCPPs with different combinations of collector and chimney radius, and the most cost-effective one was selected. In the study, the results show that the power generation of the SCPP presents apparent seasonal variation [35].

Kasaeian & Ghalamchi present a major mathematical model describing the flow. The performance evaluation of solar chimney was simulated utilizing operational and geometric configurations. It is revealed that the velocity value can be raised up to 4–25% in different cases [36]. Furthermore, the analysis suggested that the height and diameter of the chimney are the most significant physical variables for a solar chimney design. For the purpose of determining the optimum configuration of the solar chimney power plant, Dehghani and Mohammadi applied a multi-objective optimization method using revolutionary algorithm techniques. The power output and capital cost of the plant are the two objective functions which are simultaneously considered in their analysis. The results demonstrate that the power output of the plant increases linearly as the solar irradiation increases; and the increase in the ambient temperature leads to a slight decrease in the power output of the plant [37].

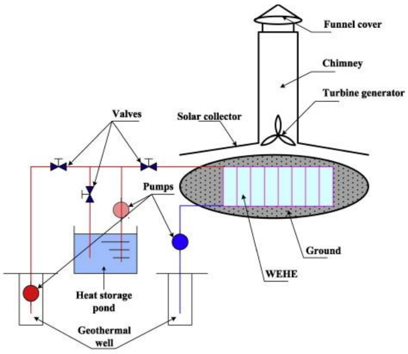
Feasibility studies [38], demonstrated that SCPP investment cost, capacity of the plant and chimney height are significant in assessing the project viability . Mathematical modeling and numerical simulation of solar chimneys using the geometric parameters of Manzanares were performed by some researchers [39]. Sangi *et al* conducted two diverse numerical simulations to evaluate the effectiveness of the model [40].

Gholamalizadeh and Kim used a three-dimensional unsteady turbulent model to analyze the effects of the solar insolation and pressure drop across the turbine on the flow and heat transfer of the system. Also, they compared the enthalpy rise through the collector and energy loss from the chimney outlet between one band and two band radiation model [41]. On the other hand, Cao *et al* investigated the performance of the geothermal–solar chimney power plant (GSCPP) with the same main dimensions as the Manzanares, in figure 2. They compared three operation models, i.e. the full solar model, the full geothermal model and the geothermal–solar combined model in normal summer and winter days and year round. Consequently, the power generation under GSM was found larger than the sum of FSM and FGM [42].

In the study, Li *et al* calculate the total net present value (TNPV) and the minimum electricity price in each phase by dividing the whole service period into four stages based on the model and certain assumptions for values of parameters.

The analysis shows that RCSCPP (Reinforced concrete solar chimney power plant) has great advantages over coal-fired power plants in stages 2-4. Furthermore, in the sensitivity analysis performed in their paper, it was found out that TNPV is very sensitive towards the changes in the solar electricity price and inflation rate, but responds only slightly to changes in carbon credits price, income tax rate and interest rate of loans. The governments should provide subsidy by setting higher electricity prices in the first stage, and then a lower electricity price in the other phases in order to encourage the development of the RCSCPPs [43].

In their study, Patel *et al* aim to optimize the geometry of the major components of the SCPP using a computational fluid dynamics (CFD). The best configuration was achieved using a chimney with a divergence angle of 2 and chimney diameter of 0.25 m alongside with a collector opening of 0.05 m and collector outlet diameter of 1 m [44]. The study of Lebbi *et al* aims to numerically investigate the airflow behaviour via a solar chimney. In their work, the researchers showed that the hydrodynamic field is directly controlled by changing the tower dimensions. Nevertheless, the thermal field is indirectly controlled by decreasing the system mean temperature [45].



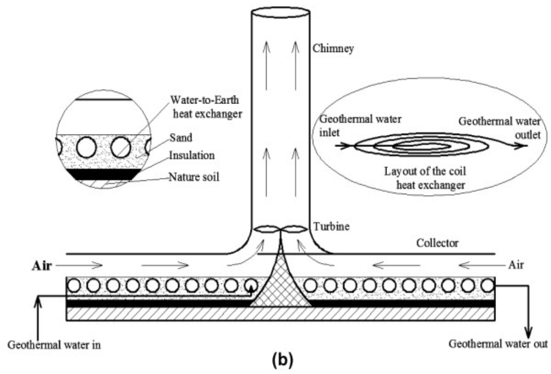


Figure 2. Geothermal solar chimney: (a) system overview (b) geothermal subsystem ([42])

Guo *et al* used a three-dimensional numerical approach with the aim of examining the influence of solar radiation, turbine pressure decrease and ambient temperature on the performance of the system. Simulation results showed that the radiation model is fundamental in preventing the overestimation of energy absorbed by the solar chimney power plant (SCPP). The predictions of the maximum turbine pressure decrease with the radiation model are more consistent with the experimental data than data neglecting the radiation heat transfer inside the collector. Furthermore, the variation of the ambient temperature has little impact on the increase of the air temperature despite its obvious effect on air velocity [46].

In the paper of Chen *et al*, a low-temperature waste heat recovery system is proposed based on the solar chimney concept. The mathematical model of the system is established based on the first law and second law of thermodynamics. Consequently, the air velocity exhibits a better stability than the mass flow rate of air and the pressure difference when the temperature of the heat source, the temperature of the ambient air or the area of heat transfer change [47].

In the paper, Cao *et al* built a program based on TRNSYS in order to simulate the performance of SCPPs. The main meteorological parameter influencing the SCPP performance is identified by means of this program. Furthermore, the configuration size design and techno-economic analysis of commercial SCPPs are performed for areas that are not included in TRNSYS database. The researchers concluded that the SCPP power generation is more relevant to the local solar irradiation than to the ambient temperature [48]. The qualities found by Guo *et al* in the literature for the ideal proportion differ between 2/3 and 0.97. Nonetheless, in this study, the ideal proportion was found to fluctuate with the intensity of solar radiation, and to be around 0.9 for the Spanish model. Also, the ideal proportions got from the analytical methodology are close those from the numerical simulation [49].

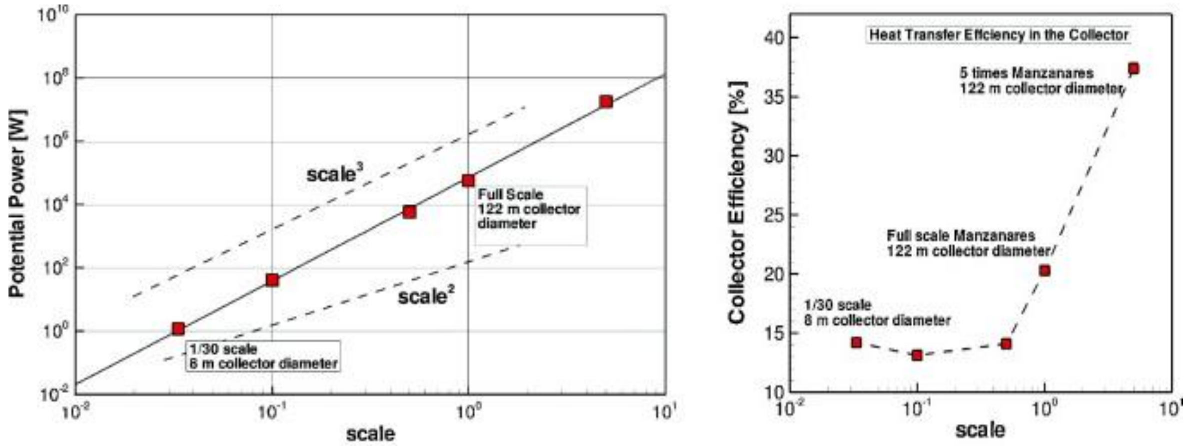


Figure 3. Available power and thermal efficiency of collector [51]

The researcher Koonsrisuk made a comparison between the conventional solar chimney power plant (CSCPP) and the sloped solar chimney power plant. The researcher found that SSCPP is thermodynamically superior to CSCPP for certain designs [50]. Fasel *et al* confirm analytical scaling laws by considering an extensive scope of scales with tower heights varying between 1 m (sub-scale laboratory model) and 1000 m (biggest imagined plant) in figure 3.

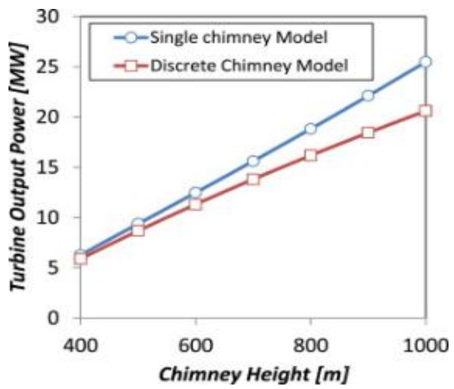


Figure 4. Chimney height-output power relation with two models [52]

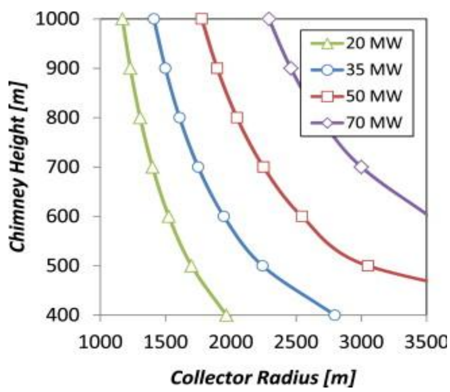


Figure 5. Chimney height-collector radius relation (I= 263 W/m^2) [52]

Both transversal and longitudinal convection rolls are distinguished in the collector, which show the existence of a Rayleigh–Be'nard–Poiseuille instability. The researchers observed a local separation close to the chimney inflow [51].

The paper of Hamdan shows a numerical thermal model for steady state airflow inside a solar chimney power plant using modified Bernoulli equation with buoyancy effect and ideal gas equation (In figure 4) [52]. The outcome demonstrates that utilizing a constant density assumption through the solar chimney can improve the analytical model; nevertheless, it over predicts the power production. The maximum power production relies on the turbine head; and the connection is not monotonic (In figure 5) [52].

In the paper of Cao *et al*, a heat transfer model that is utilized to compare the performance of a conventional solar chimney power plant (CSCPP) and two sloped solar chimney power plants (SSCPPs) with the collector oriented at 30° and 60° are analyzed. Results show that the bigger solar collector angle prompts enhanced performance in winter yet brings about lower performance in summer. The researchers found that the optimal collector angle to accomplish the most maximum power in Lanzhou, China, is around 60° [53].

In the paper of Koonsrisuk and Chitsomboon, the CFD technology is utilized to explore the progressions in flow properties brought on by the changes in the area of flow. It is discovered that the sloping collector roof influences the performance of the plant. The best possible combination between the sloping collector roof and the divergent-top chimney can create power as much as hundreds times than that of the conventional solar chimney power plant [54].

In the work conducted by Zandian and Ashjaee, a dry cooling tower and a solar chimney design are recombined to expand the thermal effectiveness of a steam Rankine cycle. The rejected warmth from the condenser into the dry cooling tower supplemented by the solar radiation gained through its transparent cover are the sources of wind energy generation that is caught by a wind turbine which is situated toward the start of the chimney. The outcomes demonstrate a maximum of 0.37 percent increment in the thermal effectiveness of a 250 MW fossil fuel power plant unit; which demonstrates that this design is a critical change in effectiveness of thermal power plants, by catching the heat that is scattered from dry cooling towers (In figure 6) [55].

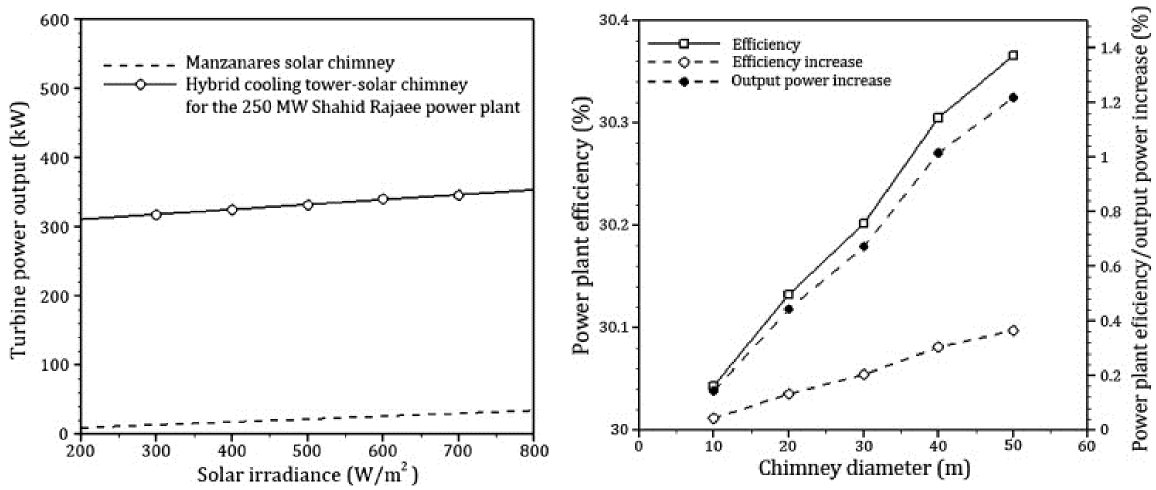


Figure 6. a) The comparison of the hybrid concept and Manzanares according to powers. b) The effect of chimney diameter on thermal power plant efficiency and percent of power increase [55]

The mathematical model of Koonsrisuk & Chitsomboon is utilized to foresee the performance attributes of large-scale commercial solar chimneys, demonstrating that the plant size, the element of pressure drop at the turbine, and solar heat flux are essential parameters for the improvement of the performance. The researchers demonstrate that the ideal proportion between the turbine extraction pressure and the accessible driving pressure for the proposed plant is circa 0.84. A straightforward technique to assess the turbine power output for solar chimney systems is also proposed in the study utilizing dimensional investigation [56].

The goal of Gholamalizadeh & Mansouri in writing the paper was to present a thorough examination including analytical and numerical models produced to anticipate the performance of a solar chimney power plant in Kerman province of Iran [57]. Their results were given in Fig. 7.

In his study, Sangi [58] aims to assess the performance of solar chimney power plants certain parts of Iran hypothetically and to project the amount of the electric energy generated. A mathematical model in view of the energy balance was created in order to project the power output of solar chimneys and additionally to inspect the impact of different surrounding conditions and structural dimensions on power production. The solar chimney power plant with a chimney height of 350 m chimney height and a collector diameter of 1000 m can create an average of 1–2 MW electric control per month throughout the year.

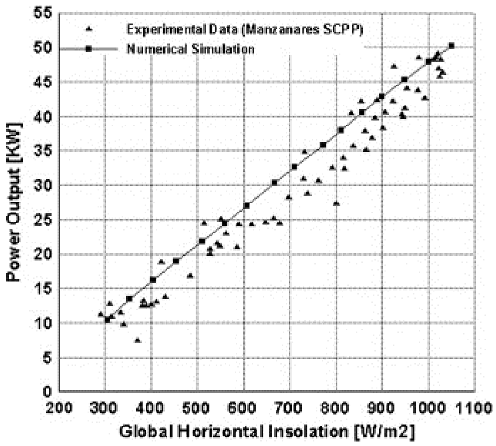


Figure 7. Comparison of measured electrical power of the prototype and the numerical simulation model [57]

Li *et al* propose an extensive hypothetical model for the performance assessment of a solar chimney power plant (SCPP); This model makes note of the impacts of flow and heat losses, and the temperature lapse rates inside and outside the chimney. There is a maximum power output for a specific SCPP under a given solar radiation condition, because of flow and heat losses and the establishment of the turbines. The power output of the turbine and the system effectiveness can then be expressed as follows (1):

$$P=\eta_t \Delta p_t Q_V \qquad \eta=P/\pi r_c^2 I_{ra} \tag{1}$$

where η_t , Qv and r_c represent the turbine total-to-total efficiency, the volume flow rate of the system and the collector radius, respectively. (I_{ra} : solar radiation [W/m^2]) [59]

Koonsrisuk develops a mathematical model for the sloped solar chimney system. Results demonstrate that utilizing a near-unity ratio of the collector inlet flow area and the collector exit flow may bring about a few issues. The researcher also examines the supposition that the density contrasts in the collector and that in the chimney are almost equal [60].

In the work conducted by Hurtado *et al*, the thermodynamic behaviour and the power output of a solar chimney power plant over a daily operation cycle is examined considering the soil as a heat storage system, via a numerical modelling under non-steady conditions. A sizeable increment of 10% in the output power is acquired when the soil compaction increments [61].

Zuo *et al* present a new solar chimney power system with combination of sea water desalination for the production of electricity and crisp water in their paper. Through hypothetical investigation, the researchers have shown that the combined system can altogether enhance the solar energy utilization efficiency and the land resources utilization efficiency, in the meantime [62]. Inclined solar chimneys and effect of the inclination angle were investigated several researchers ([63], [64], [65]. The researchers demonstrate that external winds improve the kinetic power of the emerging air [66].

In their paper, Cao *et al* designed a sloped solar chimney power plant, which is required to give electric energy to remote towns in Northwest China. The designed plant, in which the height and radius of the chimney are 252.2 m and 14 m respectively, and the radius and angle of the solar collector are 607.2 m and 31° respectively, is intended to generate 5 MW. Simulation results demonstrate that parameters of the sloped solar chimney power plant are symmetrical and stable; the power plant has a better performance in spring and autumn days; and the general productivity of the power plant is low [67].

In his study, Hamdan performed a simplified thermodynamics analytical model for enduring airflow inside a solar chimney. The investigation demonstrated that chimney height and turbine pressure head are the most critical physical variables for the solar chimney plan. A solar chimney power plant with a chimney height of 500 m and a collector roof diameter of 1000 m would create no less than 8 MW of power [68].

In their paper, Xu *et al* perform numerical simulations on air flow, heat transfer and power output properties of a solar chimney power plant model with energy storage layer and turbine like the Spanish model. The numerical simulation results uncover that when the solar radiation and the turbine productivity are 600 W/m^2 and 80%, respectively, the output power of the system can reach 120 kW. Furthermore, large mass flow rate of air flowing through the chimney outlet turn into the fundamental driver of energy loss in the system. The collector canopy also causes a lot of energy loss [69].

Bernardes and Backström performed numerical simulations in order to examine the performance of two plans of power output control applicable to solar chimney power plants. Values found in the literature for the optimum ratio of turbine pressure decrease to pressure potential change between 2/3 and 0.97. The authors demonstrate that the optimum ration is not constant all day long and it is dependent on the heat transfer coefficients applied to the collector [70]. Koonsrisuk *et al* found in their study ratio of height/radius, maximum mass flow rate and maximum power under the limitations of a fixed region and volume. The examination is approved by an extensive mathematical model [71]. Zhou *et al* propose to construct a solar chimney power plant (SCPP) in Tibet Plateau. The researchers found that if the SCPP is constructed in the plateau, it can generate twice the power an SCPP built on the same latitude of other regions [72].

The results obtained by Larbi *et al* demonstrate that the solar chimney power plant can generate from 140 to 200 kW of power on a site like Adrar amid the year, as per a projection on the monthly average of sunning [73]. Nizetic & Klarin present a simplified analytical approach for assessing the element of turbine pressure decrease in solar chimney power plants. They conclude that turbine pressure decrease factors are in the range of 0.8–0.9 for solar chimney power plants [74].

Lu Zuo *et al*, have investigated a model of wind supercharged solar chimney power plant combined with seawater desalination. The results show that, although solar chimney power plant with seawater desalination can extremely improve the solar energy extensive employment, but the power generation is decreased. The result of studies shows that in this paper, the wind pressure ventilator could remarkably increase the power generation and as well as increase the freshwater production by supplying a negative pressure at the chimney outlet [75].

Omar A *et al*, introduced a optimization of the solar chimney power density and detailed numerical examination under various operating situation, They presented a model of the solar irradiance with using the discrete ordinates (DO). The results of present numerical simulation show that the chimney collector has a most efficient radius that powerfully on the operating solar irradiance. The result of studies for optimum collector radius, efficiency and power density shows an optimum collector radius [76].

Aakash *et al*, have investigated a parametric three dimensional computational fluid dynamics (CFD) analysis of solar chimney power plant to demonstrate the effects of collector's slope and chimney diverging angle on operation of Manzanares example. The simulations results of CFD show that several numerical simulations on varying collector's slope and chimney diverging angles, the performance of solar chimney is improved. They could found although velocity and temperature increases with increasing collector's slope due to heighten heat transfer and mass flow rate, but at the same time higher collector slopes decreases the smooth air flow by developing vortices and recirculation of air, which blocks the air flow and reduce the overall performance [77].

Ayadi *et al*, performed a broad survey of the characteristics of a solar chimney power plant (SCPP) using numerical and experimental way. Their review also noted that the collector roof height is very influential on the optimization of the SCPP. In fact, results indicate an increase in the generated power while decreasing the collector roof height [78].

Cao *et al*, simulated the full-year power capacity of the conventional solar chimney power plant and sloped solar chimney power plant with maximum solar radiation angle and maximum power generation angle. They discussed the key factors influencing the collected power generation. Results indicated the system height and increase of the air flow temperature rise in the solar collector are the two major factors those determine the solar chimney power plant power capacity and accumulated power generation [79].

Rabehi *et al*, presented numerical simulations and design of solar chimney power plant. Numerical simulations and design of solar chimney power plant adopts the fan model. They investigated the impact of turbine operation and the influences of pressure drop over the turbine and solar radiation and the results show that the variation of solar radiation has an obvious effect on the flow and heat transfer characteristics [80].

Ayadi *et al*, found the impact of the numerical model on the air flow characteristics inside a solar chimney power plant. They performed computational simulations using the commercial computational fluid dynamics (CFD) code Ansys-Fluent 17.0. The results indicated that the turbulence model types affect directly the numerical results [81].

Hua *et al*, designed a novel roof solar collector to supplying hot water and space heating to enable effective collection of solar heat as well integrating naturally. They developed and validated a dynamic numerical model with experimental data [82].

Mostafa A.H *et al*, the present paper focus on the performance of the solar chimney power plant in six different locations in Saudi Arabia is investigated all over the year. They published a numerical model has been validated against experimental data and used to investigate the performance. The results show that a solar chimney power plant with 194 m chimney height and 244 m collector diameter is able of producing monthly average 56 kW electric power over a year in Riyadh city. They found that the solar chimney power plant could be an important supplement for energy in Saudi Arabia [83].

4. Conclusion

Solar chimneys gain importance especially for developing countries with large flat areas as a result of such factors as its simple structure that does not require advanced technology and the fact that it requires little maintenance. That it is used in the areas where the wind power is not economical and the opportunity to use below the collector as a greenhouse provides the collector advantage. It also stands out for the developed countries as a result of its environmental consciousness. Although it covers a large area when compared to the amount of energy it produces, the efficiency and investment costs are also improved with the developing technology. For this reason, the analysis and feasibility work and optimization gained importance.

In this study, a detailed and up-to-date literature was summarized. It was observed that in these works the number of simulations dominated numerical works is higher and the theoretical works are more prevalent by taking restricted experimental data in mathematical modelling. Here, the investment cost and the need for a large place of experimental systems are probable. It is well-known that the increase in the energy output to be obtained from the system depends on a good knowledge on the behaviours of the components in this system and the choice of heat sensitive material. Furthermore, the performance can also be improved by using the system as a hybrid system in accordance with the geographical location, meteorological conditions and economical situation. Thus, the way to solar chimney systems as a future economical environmental method will be paved.

References

[1] Backström, T. W., Harte, R., Höffer, R., Krätzig, W.B., Kröger, D.G., Niemann, H.J., Van Zijl, G.P.A.G., "State and Recent Advances in Research and Design of Solar Chimney Power Plant Technology", VGB Powertech , 2008, 88: 64-71.

[2] Wengenmayr, R., Bührke, T., "Renewable Energy", John Wiley & Sons, 2011.

[3] Ngo, C., Natowitz, J., "Our Energy Future: Resources, Alternatives and the Environment", John Wiley & Sons, 2009, 184-186.

[4] Schlaich, J., "The Solar Chimney, Edition Axel Menges", Stuttgart, 1995, 55.

[5] Haaf, W., "Solar Chimneys - Part II: Preliminary Test Results from the Manzanares Pilot Plant", International Journal of Solar Energy, 1984, 2: 141–161.

[6] Krisst, R.J.K., "Energy transfer system", Alternative Source Energy, 1983, 63: 8-11.

[7] Dhahri, A., Omri, A., "A Review of solar Chimney Power Generation Technology", International Journal of Engineering and Advanced Technology, 2013, 2: 7-12.

[8] Ghorbani, B., Ghashami, M., Ashjaee, M., Hosseinzadegan, H., "Electricity production with low grade heat in thermal power plants by design improvement of a hybrid dry cooling tower and a solar chimney concept", Energy Conversation Management, 2015, 94: 1-11.

[9] Shahreza, A.R., Imani, H., "Experimental and numerical investigation on an innovative solar chimney", Energy Conversation Management, 2015, 95: 446-452.

[10] Ghalamchi, M., Kasaeian, A., "Experimental study of geometrical and climate effects on the performance of a small solar chimney", Renewable and Sustainable Energy Reviews, 2015, 43: 425-431.

[11] Maia, C.B., Silva, G.O.C., Cabezas-Gómez, L., Hanriot, S.M., Ferreira, A.G, "Energy and exergy analysis of the airflow inside a solar chimney", Renewable and Sustainable Energy Reviews, 2013, 27: 350-361.

[12] Zuo, L., Yuan, Y., Zheng, Z.Li.Y., "Experimental research on solar chimneys integrated with seawater desalination under practical weather condition", Desalination, 2012, 298: 22-33.

[13] Kasaeian, A. B., Heidari, E.,. Vatan, S. N., "Experimental investigation of climatic effects on the efficiency of a solar chimney pilot power plant", Renewable and Sustainable Energy Reviews, 2011, 15: 5202-5206.

[14] M. Ghalamchi , A. Kasaeian , M. Ghalamchi , N. Fadaei , R. Daneshazarian, "Optimizing of solar chimney performance using electrohydrodynamic system based on array geometry", Energy Conversion and Management, 2017, 135: 261–269.

[15] Hussain H. Al-Kayiema, K.V. Sreejayaa, Aja O. Chikereba, "Experimental and numerical analysis of the influence of inletconfiguration on the performance of a roof top solar chimney", Energy and Buildings 2018, 159: 89–98.

[16] A. Bouabidi , A. Ayadi , H. Nasraoui , Z. Driss , M. S. Abid, "Study of solar chimney in Tunisia: Effect of the chimney configurations on the local flow characteristics", Energy & Buildings, 2018, 169: 27–38.

[17] N. Fadaei , A. Kasaeian , A. Akbarzadeh , S. H. Hashemabadi, "Experimental investigation of solar chimney with phase change material (PCM) ", Renewable Energy, 2018, 123: 26-35.

[18] Pasumarthi, N., Sherif, S.A., "Experimental and theoretical performance of a demonstration solar chimney model Part I: Mathematical model development", International Journal Energy Research, 1998, 22: 277-288.

[19] Bernardes, M. A., Voss, A., Weinrebe, G., "Thermal and technical analyses of solar chimneys", Solar Energy, 2003, 75: 511-524.

[20] Backström, T.W., Fluri, T.P., "Maximum fluid power condition in solar chimney power plants – An analytical approach", Solar Energy, 2006, 80: 1417–1423.

[21] Sakonidou, E. P., Karapantsios, T. D., Balouktsis, A. I., Chassapis, D., "Modeling of the optimum tilt of a solar chimney for maximum air flow", Solar Energy, 2008, 82: 80–94.

[22] Ming, T., Liu, W., Pan, Y., Xu, G., "Numerical analysis of flow and heat transfer characteristics in solar chimney power plants with energy storage layer", Energy Conversation Management, 2008, 49: 2872-2879.

[23] Tingzhen, M., Wei, L., Guoling, X., Yanbin, X., Xuhu, G., Yuan, P., "Numerical simulation of the solar chimney power plant systems coupled with turbine", Renewable Energy, 2008, 33: 897-905.

[24] Fluri, T.P., Backström, T.W., "Performance analysis of the power conversion unit of asolar chimney power plant", Solar Energy, 2008, 999-1008.

[25] Petela, R., "Thermodynamic study of a simplified model of the solar chimney power plant", Solar Energy, 2009, 94: 94-107.

[26] Maia, C.B., Ferreira, A.G., Valle, R.M., Cortez, M.F.B., "Theoretical evaluation of the influence of geometric parameters and materials on the behavior of the airflow in a solar chimney", Comput. Fluids, 2009, 38: 625–636.

[27] Zhou, X., Yang, J., Xiao, B., Hou, G., Xing, F., "Analysis of chimney height for solar chimney power plant", Applied Thermal Engineering , 2009, 29: 178–185.

[28] Bernardes, M.A., Backström, T.W., Kröger, D.G., "Analysis of some available heat transfer coefficients applicable to solar chimney power plant collectors", Solar Energy, 2009, 83: 267-275.

[29] Fluri, T.P., Pretorius, J.P., Van Dyk, C., Backström, T.W., Kröger, D.G., Van Zijl, G.P.A.G., "Cost analysis of solar chimney power plants", Solar Energy, 2009, 246-256.

[30] Zhou, X., Yang, J., Ochieng, R., Xiao, X. Li. B., "Numerical investigation of a plumefrom a power generating solar chimney in an atmospheric cross flow", Atmospheric Research , 2009, 91: 26-35.

[31] Ghorbani, B., Ghashami, M., Ashjaee, M., Hosseinzadegan, H., "Electricity production with low grade heat in thermal power plants by design improvement of a hybrid dry cooling tower and a solar chimney concept", Energy Conversation Management, 2015, 94: 1-11.

[32] Zou, Z., He, S., "Modeling and characteristics analysis of hybrid cooling-tower-solar-chimney system", Energy Conversation Management, 2015, 95: 59-68.

[33] Zandian, A., Ashjaee, M., "The thermal efficiency improvement of a steam Rankine cycle by innovative design of a hybrid cooling tower and a solar chimney concept", Renewable Energy, 2013, 51: 465-473.

[34] Naraghi, M. H., Blanchard, S., "Twenty-four hour simulation of solar chimneys", Energy and Buildings., 2015, 94: 218-226.

[35] Guo, P., Li, J., Wang, Y., "Annual performance analysis of the solar chimney power plant in Sinkiang, China", Energy Conversation Management, 2014, 87: 392-399.

[36] Kasaeian, A., Ghalamchi, M., "Simulation and optimization of geometric parameters of a solar chimney in Tehran", Energy Conversation Management, 2014, 83: 28-34.

[37] Dehghani, S., Mohammadi, A. H., "Optimum dimension of geometric parameters of solar chimney power plants – A multi-objective optimization approach", Solar Energy, 2014, 105: 603-612.
[38] Nizetic, S., Ninic, N., Klarin, B., "Analysis and feasibility of implementing solar chimney power plants in the Mediterranean region", Energy , 2008, 33: 1680-1690.
[39] Okoye, C.O., Atikol, U., "A parametric study on the feasibility of solar chimney power plants in North Cyprus conditions", Energy Conversation Management, 2014, 80: 178-187.
[40] Sangi, R., Amidpour, M., Hosseinizadeh, B., "Modeling and numerical simulation of solar chimney power plants", Solar Energy, 2011, 85: 829-838.
[41] Gholamalizadeh, E., Kim, M., "Three-dimensional CFD analysis for simulating the greenhouse effect in solar chimney power plants using a two-band radiation model", Renewable Energy, 2014, 63: 498-506.
[42] Cao, F., Li, H., Ma, O., Zhao, L., "Design and simulation of a geothermal–solar combined chimney power plant", Energy Conversation Management, 2014, 84: 186-195.
[43] Li, W., Wei, P., Zhou, X., "A cost-benefit analysis of power generation from commercial reinforced concrete solar chimney power plant", Energy Conversation Management, 2014, 79: 104-113.
[44] Patel, S.K., Prasad, D., Ahmed, M.R., "Computational studies on the effect of geometric parameters on the performance of a solar chimney power plant", Energy Conversation Management, 2014, 77: 424-431.
[45] Lebbi, M., Chergui, T., Boualit, H., Boutina, I., "Influence of geometric parameters on the hydrodynamics control of solar chimney", International Journal of Hydrogen Energy, 2014, 39: 15246-15255.
[46] Guo, P., Li, J., Wang, Y., "Numerical simulations of solar chimney power plant with radiation model", Renewable Energy, 2014, 62: 24-30.
[47] Chen, K., Wang, J., Dai, Y., Liu, Y., "Thermodynamic analysis of a low-temperature waste heat recovery system based on the concept of solar chimney", Energy Conversation Management, 2014, 80: 78-86.
[48] Cao, F., Li, H., Zhao, L., Bao, T., Guo, L., "Design and simulation of the solar chimney power plants with TRNSYS", Solar Energy, 2013, 98: 23-33.
[49] Guo, P., Li,J., Wang,Y., Liu,Y., "Numerical analysis of the optimal turbine pressure drop ratio in a solar chimney power plant", Solar Energy, 2013, 98: 42-48.
[50] Koonsrisuk, A., "Comparison of conventional solar chimney power plants and sloped solar chimney power plants using second law analysis", Solar Energy, 2013, 98: 78-84.
[51] Fasel, H.F., Meng, F., Shams, E., Gross, A., "CFD analysis for solar chimney power plants", Solar Energy, 2013, 98: 12-22.

[52] Hamdan, M.O., "Analysis of solar chimney power plant utilizing chimney discrete model", Renewable Energy, 2013, 56: 50-54.
[53] Cao, F., Zhao, L., Li, H., Guo, L., "Performance analysis of conventional and sloped solar chimney power plants in China", Applied Thermal Engineering, 2013, 50: 582-592.
[54] Koonsrisuk, A., Chitsomboon, T., "Effects of flow area changes on the potential of solar chimney power plants", Energy, 2013, 51: 400-406.
[55] Zandian A. and Ashjaee M., "The thermal efficiency improvement of a steam Rankine cycle by innovative design of a hybrid cooling tower and a solar chimney concept", Renewable Energy, 51(C): 465-473.
[56] Koonsrisuk, A., Chitsomboon, T., "Mathematical modeling of solar chimney power plants", Energy, 2013, 51: 314-322.
[57] Gholamalizadeh, E., Mansouri, S. H., "A comprehensive approach to design and improve a solar chimney power plant: A special case – Kerman Project", Applied Energy, 2013, 102: 975-982.

[58] Sangi, R., "Performance evaluation of solar chimney power plants in Iran", Renewable and Sustainable Energy Reviews, 2012, 16: 704-710.
[59] Li, J., Guo, P., Wang, Y., "Effects of collector radius and chimney height on power output of a solar chimney power plant with turbines", Renewable Energy, 2012, 47: 21-28.
[60] Koonsrisuk, A., "Mathematical modeling of sloped solar chimney power plants", Energy, 2012, 47: 582-589.
[61] Hurtado, F.J., Kaiser, A.S., Zamora, B., "Evaluation of the influence of soil thermal inertia on the performance of a solar chimney power plant", Energy, 2012, 47: 213-224.
[62] Zuo, L., Zheng, Y., Li, Z., Sha, Y., "Solar chimneys integrated with sea water desalination", Desalination, 2011, 276: 207-213.
[63] Saifi, N., Settou, N., Dokkar, B., Negrou, B., Chennouf, N., "Experimental study and simulation of airflow in solar chimneys", Energy Procedia, 2012, 18: 1289-1298.
[64] Bilgen, E., Rheault, J., "Solar chimney power plants for high latitudes", Solar Energy, 2005, 79: 449–458.
[65] Al-Kayiem, H.H., Sreejaya, K.V., Gilani, S.I., "Mathematical analysis of the influence of the chimney height and collector area on the performance of a roof top solar chimney", Energy and Buildings, 2014, 68: 305-311.
[66] Panse, S.V., Jadhav, A.S., Gudekar, A.S., Joshi, J. B., "Inclined solar chimney for power production", Energy Conversation Management, 2011, 52: 3096-3102.
[67] Cao, F., Zhao, L., Guo, L., "Simulation of a sloped solar chimney power plant in Lanzhou", Energy Conversation Management, 2011, 52: 2360-2366.
[68] Hamdan, M. O., "Analysis of a solar chimney power plant in the Arabian Gulf region", Renewable Energy, 2011, 36: 2593-2598.
[69] Xu, G., Ming, T., Pan, Y., Meng, F., Zhou, C., "Numerical analysis on the performance of solar chimney power plant system", Energy Conversation Management, 2011, 52: 876-883.
[70] Bernardes, M. A., Backström, T.W., "Evaluation of operational control strategies applicable to solar chimney power plants", Solar Energy, 2010, 84: 277-288.
[71] Koonsrisuk, A., Lorente, S., Bejan, A., "Constructal solar chimney configuration", International Journal of Heat and Mass Transfer, 2010, 53: 327-333.
[72] Zhou, X., Wang, F., Fan, J., Ochieng, R.M., " Performance of solar chimney powe plant in Qinghai-Tibet Plateau", Renewable and Sustainable Energy Reviews, 2010, 14: 2249-225.
[73] Larbi, S., Bouhdjar, A., Chergui, T., "Performance analysis of a solar chimney power plant in the southwestern region of Algeria", Renewable and Sustainable Energy Reviews, 2010, 14: 470-477.
[74] Nizetic, S., Klarin, B., "A simplified analytical approach for evaluation of the optimal ratio of pressure drop across the turbine in solar chimney power plants", Applied Energy, 2010, 87: 587-591.
[75] Zuo, L., Ding, L., Chen, J, Xiaotian Zhou, Bofeng Xu, Zihan Liu, "Comprehensive study of wind supercharged solar chimney power plant combined with seawater desalination", Solar Energy, 2018, 166: 59–70.
[76] Omar, A., Najm, S. Shaaban, "Numerical investigation and optimization of the solar chimney collector performance and power density", Energy Conversion and Management, 2018, 168: 150–161.
[77] Aakash, H., Majid, A., Adeel, W., "Numerical investigation on performance of solar chimney power plant by varying collector slope and chimney diverging angle", Energy, 2018, 142: 411-425.
[78] Ayadi, A., Bouabidi, A., Driss, Z., Abid, M.S, "Experimental and numerical analysis of the collector roof height effect on the solar chimney performance", Renewable Energy, 2018, 115: 649-662.
[79] Cao, F., Liu, Q., Yang, T., Zhu, T., Bai, J., Zhao, L, "Full-year simulation of solar chimney power plants in Northwest China", Renewable Energy, 2018, 119: 421-428.

[80] Rabehi, R., Chaker, A., Ming, T., Gong, T, "Numerical simulation of solar chimney power plant adopting the fan model", Renewable Energy, 2018, 126: 1093-1101.

[81] Ahmed Ayadi, Haithem Nasraoui, Abdallah Bouabidi, Zied Driss, Moubarak Bsisa, Mohamed Salah Abid, "Effect of the turbulence model on the simulation of the air flow in a solar chimney", International Journal of Thermal Sciences, 2018, 130: 423–434.

[82] Hua, ZH., Luo, B., He, W., Hub, D., Ji, J., Ma, J, "Performance study of a dual-function roof solar collector for Chinese traditional buildings application", Applied Thermal Engineering, 2018, 128: 179–188.

[83] Mostafa A.H. Abdelmohimen, Salem A. Algarni, "Numerical investigation of solar chimney power plants performance for Saudi Arabia weather conditions", Sustainable Cities and Society, 2018, 38: 1–8.