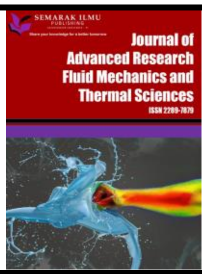
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



The Effect of The Inclusion of The Secondary Roof Under the Main Roof on Performance of Chimney Solar Power Plants

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ARTICLE INFO

Article history:
Received 20 March 2022
Received in revised form 28 June 2022
Accepted 10 July 2022
Available online 2 August 2022

Keywords:
Solar Chimney Power Plant (SCPP); solar collector; collector roof

ABSTRACT

In this work the effect of the inclusion a second roof on the power output of chimney solar power plant (SCPP) were investigated numerically through analytical model. The analytical model presented in this work based on energy balance equations and mass conservation equation at steady state. In second step, the proposed analytical model is then used to estimate the annual electricity production in Sétif, a region of Algeria. For the position of the sun in Setif is 36.19 degrees longitude and 5.41 degrees latitude. It appears from results obtained that the efficiency is increased by 28.7 % for the chimney solar power plant (SCPP) with the secondary roof compared to chimney solar power plant (SCPP) without second roof. It was also concluded that there is an optimal height of the second roof for the power output of chimney solar power plant (SCPP) to remain maximum. It is noted that the energy production increases with the increase in radiation and ambient temperature. However, the solar irradiation is the dominant factor on the electricity production of the chimney solar power plant, compared to the ambient temperature. The results obtained are in good agreement with the experimental results of a prototype plant in MANZANARES.

1. Introduction

The solar chimney power plant (SCPP) is one of the most promising technologies, with a simple design and low-cost advantages for power production. In order to produce electricity, the SCPP uses a sophisticated heat transfer technique to transform solar radiation energy into electric current. The SCPP is eco-friendly. The first SCPP prototype was created by the German company, Schlaich [1] in MANZANARES, Spain, in 1981 with a peak power of 50 kW. A lot of theoretical and experimental studies have been done to improve the thermal performance of a solar chimney by changing some design parameters. Through experimental and numerical simulations. Ikhlef *et al.,* [2] have analyzed the effect of environmental factors on the performance of a prototype of a solar chimney with a thermal storage system for different meteorological data. The obtained results showed that the global horizontal irradiance, the temperature, the relative humidity, and the wind velocity influence the power output. Likewise**,** Abdelsalam *et al.,* [3] proposed a new design of chimney solar power

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https://doi.org/10.37934/arfmts.98.1.157170

plant (SCPP). The design of the SCPP has been modified by adding a concentric secondary external chimney to the structure of the SCPP to improve power generation, the internal chimney functions as a traditional SCPP to generate electricity during the day while the chimney external secondary works as 10 cooling towers in a series. Each cooling tower is equipped with a turbine and water sprinklers for additional power generation. A mathematical model that includes the energy and mass balance equations of the system was built using MATLAB. The new design system produced up to 993 MWh of electrical energy, which is 2.6 times more than the traditional SCPP. Likewise, Choi *et al.,* [4] studied the effect of water storage system in SCPP. A water storage system was installed under the collector to conserve thermal energy overnight. Larbi *et al.,* [5] have analyzed the performance of a solar power plant with a chimney supposed to supply electricity to isolated villages located in the south-west region of Algeria. The results obtained show that the chimney solar power plant can produce 140 to 200 kW of electricity on a site like Adrar during the year, according to an estimate made on the monthly sunshine average. This production is sufficient for the needs of isolated areas. Li *et al.,* [6] have proposed a theoretical model for the evaluation of the performance of a solar power plant (SCPP). This model takes into account the effects of flow and heat losses, as well as the rates of temperature difference inside and outside the stack. The results obtained show that a limitation of the maximum collector radius exists for the maximum attainable power of the SCPP; whereas no such limitation exists for the height of the chimney in terms of contemporary building technology. Choi *et al.,* [7] have developed a new mathematical model for calculating the power output of SCPP, taking into account realistic physical pressure drops across the entire SCPP system. The new analytical model was validated by experimental data from the prototype plant in MANZANARES Spain. Aissaoui *et al.,* [8] in first step, an experimental study was carried out using thermocouples to measure the temperature distributions on the solar air heater of the SCPP. The different measured temperatures of the absorber plate, the airflow and the bottom plate are used to determine the local convective heat transfer coefficients. In a second step, the problem is dealt with numerically by a FORTRAN code developed to calculate, for different intensities of solar radiation, the temperature variations in each of the components of the solar air panel. A satisfactory qualitative and quantitative agreement is obtained between the numerical and experimental results. Attig-Bahara *et al.,* [9] studied the effect of thermal storage on the performance of the SCPP using an internal code. The results show that the ratio between the energies released and stored depends mainly on the season and the energy production is increased by about 35% compared to a system without storage. The results demonstrate the importance of including long-term thermal storage when modeling SCPP. Baral [10] conducted a mathematical study for the estimation of electricity production in the Nepalese context. Performance influencing power output as a function of turbine pressure ratio, thermal conductivity and specific heat capacity of soil and mass flow rate were also estimated. The results showed that the power developed by the air, the power of the turbines and the electric power are respectively 120.66 kW and 44 kW. The power developed is estimated when the height and radius of the stack were 190 and 5 m respectively. Also noted that ambient temperature and air velocity also play an important role in energy production. Tayebi and Djezzar [11] carried out a numerical analysis of the collector of the solar chimney, in order to examine the effect of the variation of the ambient temperature and of the solar radiation on the flow in the collector. A mathematical model based on continuity, Navier-Stokes and energy equations has been developed to determine in detail the collector mechanism of the chimney solar power plant. The distribution of temperature, velocity and pressure in the solar collector is illustrated for the city of Adrar southern Algeria. The results obtained in good agreement with the experimental data of the prototype of MANZANARES. Ghalamchi *et al.,* [12] have realized a small-scale experimental solar chimney in an air collector of 3 m in diameter and a chimney of 2 m in height was built. In the next step, the imperialist competitive algorithm method was applied as an artificial intelligence approach to predict temperature changes due to radiation variations. Finally, according to the value correlation coefficient and the root mean square error, the results of the trained networks were reported and the temperature prediction was performed with high accuracy. The results showed that the experimental data of the solar chimney was qualified as noiseless. Dai a *et al.,* [13] analyzed, some parameters, such as stack height, solar collector diameter, ambient temperature, solar irradiance and wind turbine efficiency on power generation performance. Three counties' regions of China have been selected as pilot locations to build a solar power plant. Cuce *et al.,* [14] have studied the impacts of the different slope angles of the ground, on the performance of the SCPP, through reliable CFD software ANSYS FLUENT. However, when the ground slope is made 0.5°, it is observed that the maximum velocity increases by 37% to 19.51 m/s, and the power output is enhanced to 63.95 kW with a rise of 17.7%. Sloping ground is found a key solution to improve the turbulent effects inside the plant, thus to enhance the electrical power output. Cuce *et al.,* [15] have analysed influence of area ratio of the chimney on main performance parameters of solar chimney power plants (SCPP) through a justified 3D axisymmetric CFD model. The results reveal that area ratio plays a vital role in performance of SCPP. Kasaeian *et al.,* [16] through a fundamental mathematical model that describes the flow was presented, and the performance evaluation of solar chimney was simulated with operational and geometric configurations. The analysis indicated that the height and diameter of the chimney are the most important physical variables for solar chimney design. Nasraoui *et al.,* [17] analyze the effect of the divergent chimney shape on the airfow behavior inside SCPP. The obtained results confirm that the divergence shape affects directly the efficiency of the SCPP. Moreover, the hyperboloid chimney presents the efficient solution which produces an important power output with keeping the chimney height constant. Likewise, Hassan *et al.,* [18] have a parametric three dimensional computational fluid dynamics (CFD) analysis of solar chimney power plant was performed to illustrate the effects of collector's slope and chimney diverging angle on performance of MANZANARES prototype. Based on computed results, it was discovered that both velocity and temperature increase with increasing collector's slope due to enhanced heat transfer and mass flow rate, but simultaneously higher collector slopes also deteriorate the smooth air flow by developing vortices and recirculation of air, which obstructs the air flow and may reduce the overall performance. Too and Azwadi [19] analyzed the effect of an inclined chimney and also the effect of different solar radiation on performance of updraft tower power plant (SUTPP). Jawad *et al.,* [20] investigated the influence of divergent solar chimney on solar chimney performance. The experiments show that divergent solar chimney increases the theoretical power generation potential and improves the stalk effect and have higher outlet velocity compared to a cylindrical solar chimney. This study finds that a shorter divergent solar chimney produces greater energy compared to a higher cylindrical solar chimney. Kinan and Sidik [21] studied experimentally solar updraft tower power plant (SUTPP) to be used in rural areas of developing countries. Saadun *et al.,* [22] analyzed the influence some parameters of the geometry of the solar updraft tower power plant (SUTPP) as slope angle of collector, inlet height of collector, and diameter of chimney on the performance of the solar updraft tower power plant (SUTPP).

The aim of the present study is the investigation of the effect of inclusion a second roof on the power output of SCPP, through an analytical model. The analytical model presented in this work based on energy balance equations and mass conservation equation at steady state. The proposed analytical model is then used to estimate the annual electricity production in Sétif, a region of Algeria in second stage. For the position of the sun in Setif is 36.19 degrees longitude and 5.41 degrees latitude. The results are compared with the SCPP without second roof to show the improvement in performance.

2. Thermal Analysis Model

Solar radiation is used as fuel by the solar chimney collector to heat the working fluid. To generate an air circulation channel, the collector is made up of a transparent cover glass elevated above the ground. The function of the collector cover is to transmit the radiant power obtained to heat the ground and the ambient air circulating between the two. The heated floor reflects the energy to increase the air flow's radiation.

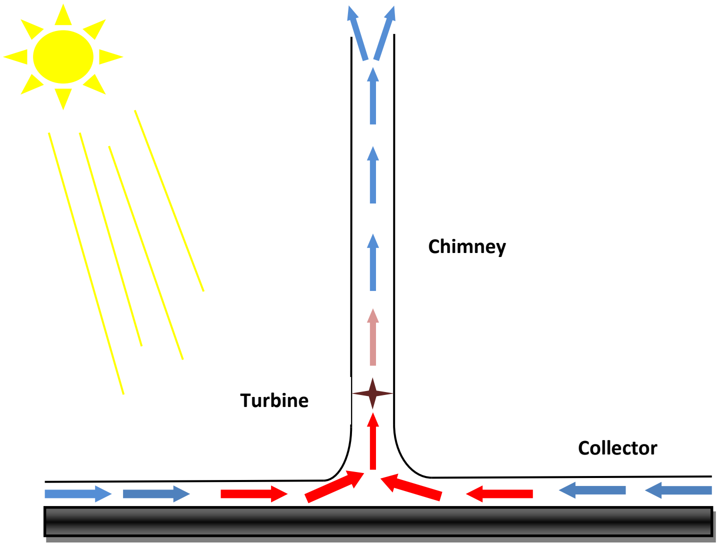

Fig. 1. Solar chimney power plant schematic representation

2.1 Assumptions of The Study

The proposed method analytical is based on these assumptions

i. Air is an ideal gas
ii. Steady state flow
iii. Flow radially one-dimensional flow under collector
iv. Solar irradiation was the only source of heat
v. The heat absorbed in the collector roof and the ground are assumed to transfer heat into the air stream by convective heat transfer
vi. Radiative heat emissions from the collector roof and the ground have also been taken into account.

2.2 Thermal Analysis Without Secondary Roof

The schematic diagram of heat transfer in the collector without a secondary roof is shown in Figure 2. Solar radiation heats the roof and ground of the collector, and then transfers the heat to the air circulating in the collector. The heat transfer equation is

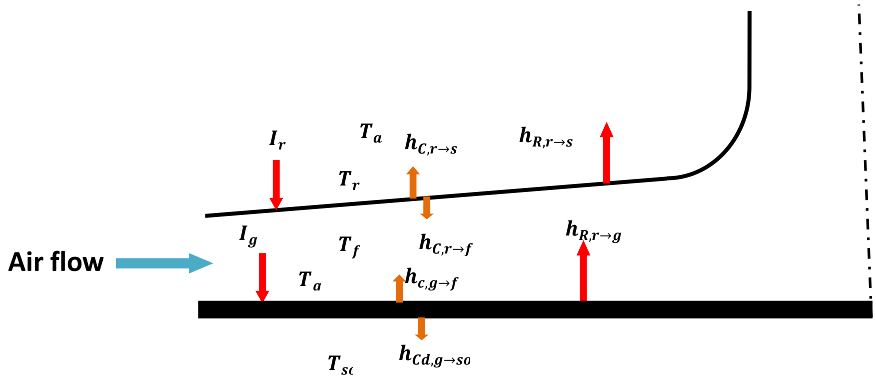

Fig. 2. Thermal analysis of the collector without second roof

Roof: $$I_r + h_{R,g\to r}(T_g - T_r) + h_{C,f\to r}(T_f - T_r) = (h_{C,r\to s} + h_{R,r\to s})(T_r - T_a) \quad (1)$$

Air: $$h_{C,r\to f}(T_r - T_f) + h_{C,g\to f}(T_g - T_f) = \frac{\dot{m}Cp}{2\pi r}\frac{\Delta T_f}{\Delta r} \quad (2)$$

Ground: $$I_g + h_{C,f\to g}(T_f - T_g) + h_{R,r\to g}(T_r - T_g) = h_{Cd,g\to so}(T_g - T_{so}) \quad (3)$$

Eq. (1), Eq. (2) and Eq. (3) refer to the heat transfer equilibrium equation for roof, air and ground, respectively. Where I_r is the incident solar irradiation for collector, T_g is the ground temperature, T_r is the collector roof temperature, T_f is the air flow temperature, I_g is the solar radiation absorbed by the ground, $h_{C,r\to s}$ and $h_{R,r\to s}$ are the overall heat loss coefficients in the top of the collector roof, $h_{Cd,g\to so}$ is the ground loss coefficient.$h_{R,g\to r}$, $h_{C,f\to r}$ and $h_{C,r\to f}$ are the heat transfer coefficients between the ground and the collector roof, the collector roof and air flowing inside the collector, and the collector roof and air flowing inside the collector, respectively. The complication arising from the heat balance equation presented above is that there is no straight-forward analytical solution for solving the temperatures T_r, T_g and T_f. For this reason, numerical iteration solution is imperative, in which guess temperature values are initially utilized.

The incident solar radiation on the collector roof I_r and the ground absorber I_g is given as:

$$I_r = \alpha_1 I \quad (4)$$

$$I_g = \alpha_2 \tau_1 I \quad (5)$$

where α_1 is the absorptivity of the collector roof, I is the available solar irradiation, α_2 and τ_1 are the corresponding absorptivity of the ground and transmissivity of the collector roof, respectively.

The wind convective heat transfer $h_{C,r\to s}$ is given [23]

$$h_{C,r\to s} = 5.67 + 3.86V \quad (6)$$

The radiation heat transfer coefficient between the collector cover and the sky $h_{R,r\to s}$, expressed by Pasumarthi and Sherif [23] as

$$h_{R,r\to s} = \sigma\varepsilon_1(T_{sky} + T_r)(T_{sky}^2 + T_r^2)\left(\frac{T_r - T_{sky}}{T_r - T_a}\right) \quad (7)$$

where V is site location wind speed, and ε_1 is the emissivity of the collector roof, T_{sky} is the sky temperature expressed by Larbi *et al.,* [5]

$$T_{sky} = 0.0552(T_a)^{1.5} \tag{8}$$

The radiation heat transfer coefficient between the roof and the ground absorber can be estimated by [5]

$$h_{R,g\to r} = \frac{\sigma(T_g+T_r)(T_g^2+T_r^2)}{\frac{1}{\varepsilon_2}+\frac{1}{\varepsilon_1}-1} \tag{9}$$

$\varepsilon_2$is the emissivity of the ground and σ is Stefan–Boltzmann constant. The free convection heat transfer coefficient between the collector roof and the air flow, $h_{C,r\to f}$ and that between the absorber plate and the air flow, $h_{C,g\to f}$ are calculated using

$$h_{C,g\to f}/h_{C,r\to f} = Nu\frac{k_{air}}{D_h} \tag{10}$$

where Nu is Nusselt number, k_{air} is thermal conductivity of the air and D_h is the hydraulic diameter.

The ground loss coefficient $h_{Cd,g\to so}$ is estimated by [24]

$$h_{Cd,g\to so} = 2\left(\frac{k\rho Cp}{\pi t}\right)^{0.5} \tag{11}$$

where t is the hour from midnight and $r = \frac{D_h}{2}$.

The following empirical equations can be used to estimate air density ρ, thermal conductivity k, specific heat capacity C_p and dynamic viscosity μ [25]

$$\rho = 3.9147 - 0.01082T + 2.9013\times10^{-5}T^2 - 1.9407\times10^{-8}T^3 \tag{12}$$

$$k = (0.0015215 + 0.097459T - 3.3322\times10^{-5}T^2)T^{-6} \tag{13}$$

$$C_p = 1002.5 + 275\times10^{-6}(T-200)^2 \tag{14}$$

$$\mu = 1.458\times10^{-6}\frac{T^{1.5}}{T+110.4} \tag{15}$$

So, the collector efficiency is given by

$$\eta_{coll} = \frac{h_{C,r\to f}(T_r-T_f)+h_{C,g\to f}(T_g-T_f)}{I} \tag{16}$$

2.3 Thermal Analysis with Secondary Roof

The schematic diagram of heat transfer in the SCPP with a secondary roof is shown in Figure 3. The heat transfer equation is

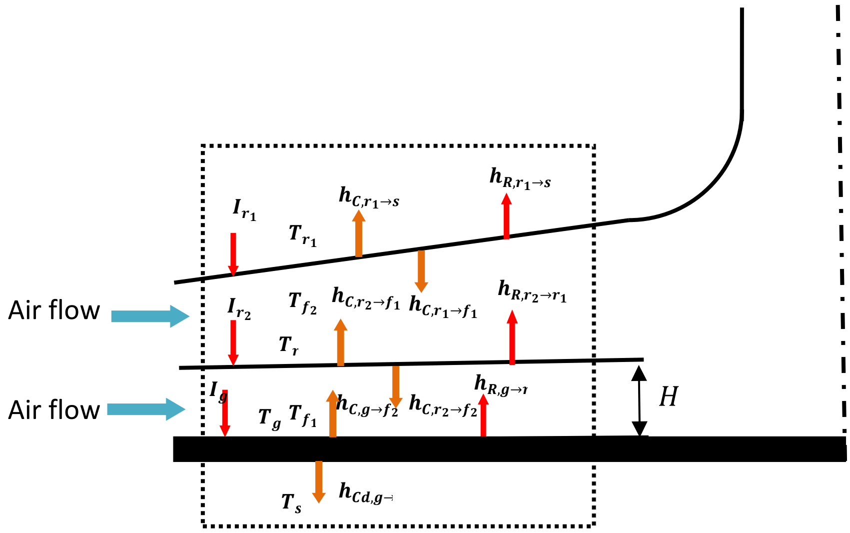

Fig. 3. Thermal analysis of the collector with second roof

$$Roof1: I_{r1} + h_{R,r_2\to r_1}(T_{r_2} - T_{r_1}) = h_{C,r_1\to s}(T_{r_1} - T_s) + h_{C,r_1\to f1}(T_{r_1} - T_{f1}) + h_{R,r_1\to s}(T_{r_1} - T_s) \quad (17)$$

$$Air1: h_{C,r_1\to f1}(T_{r_1} - T_{f1}) + h_{C,r_2\to f1}(T_{r_2} - T_{f1}) = \frac{\dot{m}Cp}{2\pi r}\frac{\Delta T_{f1}}{\Delta r} \quad (18)$$

$$Roof2: I_{r_2} + h_{R,g\to r_2}(T_g - T_{r_2}) = h_{C,r_2\to f1}(T_{r_2} - T_{f1}) + h_{C,r_2\to f2}(T_{r_2} - T_{f2}) + h_{R,r_2\to r_1}(T_{r_2} - T_{r_1}) \quad (19)$$

$$Air2: h_{C,r_2\to f2}(T_{r_2} - T_{f2}) + h_{C,g\to f2}(T_g - T_{f2}) = \frac{\dot{m}Cp}{2\pi r}\frac{\Delta T_{f2}}{\Delta r} \quad (20)$$

$$Ground: I_g + h_{C,f2\to g}(T_{f2} - T_g) = h_{Cd,g\to so}(T_g - T_{so}) + h_{R,g\to r_2}(T_g - T_{r_2}) \quad (21)$$

The index 1 and 2 correspond to the primary and secondary roof respectively. So, the temperatures in Eq. (1) to Eq. (3) and Eq. (17) to Eq. (21) are solved iteratively, and the newly calculated temperatures are compared to the previous values until they converge. The convergence tolerance is set in such a way that the difference between the new temperature and guessed temperature is less than 0.01 K.

2.4 Chimney Model

The hot air (thermal energy) from the collector is transformed into kinetic energy in the chimney. The pressure difference occurs between the base of the chimney and the surroundings due to the change in frontal area as the heated air enters the chimney, and from Bernoulli's equation the pressure drops ΔP_{turb} across the turbine can be expressed in terms of the total pressure difference as

$$\Delta P_{turb} = \Delta P_{tot} - \Delta P_{drop} \quad (22)$$

$$\Delta P_{drop} = \frac{\rho_{air_{out}} V_{ch}^2}{2} \quad (23)$$

The total pressure ΔP_{tot} is the sum of both the dynamic $\Delta P_{dynamic}$ and static pressure ΔP_{static}. The static pressure is equal to zero, hence [26]

$$\Delta P_{tot} = \Delta P_{dynamic} = \rho_{air_{out}}\, gH_{ch}\frac{\Delta T}{T_a} \tag{24}$$

The air flow velocity V_{ch} at the inlet of the chimney is estimated by [27]

$$V_{ch} = \sqrt{\frac{2gH_{ch}\Delta T}{3T_{air}}} \tag{25}$$

The efficiency of the chimney η_{ch} is estimated by [5]

$$\eta_{ch} = \frac{gH_{ch}}{C_p T_{air}} \tag{26}$$

2.5 Output Power of SCPP

A turbine at the base of the solar tower power plant is propelled by the airflow through the tower. The turbine drives a generator that produces electricity. For maximum power on the system, the pressure ratio across the turbine performs a critical role in calculating the overall performance. Many researchers have supposed that the optimal values of the pressure ratio are $^2/_3$. The electrical power output P_{ele} from the SCPP is calculated as

$$P_{ele} = {}^2/_3\, I\, A_{coll}\eta_{coll}\, \eta_{ch} \tag{27}$$

where A_{coll} is the area of the solar collector, note that

$$A_{coll} = \frac{\pi D_{coll}^2}{4} \tag{28}$$

D_{coll} is the diameter of the collector.

3. Results and Discussion

The overall energy performance of the SCPP was calculated from our thermal analysis model using FORTRAN. The algorithm was used to determine the air pressure, temperature, and density at specific locations of the SCPP. Then the conservation of the mass flow of the system is used in this algorithm. This iteration process of algorithm was used to calculate the power output of the SCPP, until there was only a slight discrepancy between the current temperature value and the prior temperature value to evaluate.

3.1 Validation of the Model Developed from the Experimental Data of MANZANARES Prototype

To validate our analytical model used in this work, the experimental data on solar irradiation and ambient temperature of Haaf [28] at MANZANARES on 2 September 1982 was used, as indicated in Figure 4. The main dimensions of the Spanish prototype are listed in Table 1.

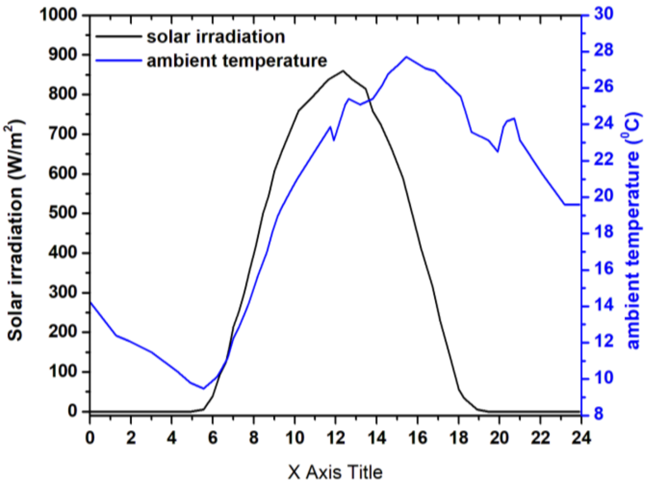

Fig. 4. Data solar irradiation and ambient temperature at MANZANARES on 2 September 1982

Table 1
Dimensions of the Spanish prototype solar chimney power plant

Dimension	Specification
Tower height	195 m
Tower radius	5.8 m
Collector radius	122 m
Collector inlet radius	1.87 m
Collector outlet height	1.87 m

Calculated results of SCPP power output and collector temperature rise were compared with experimental results of MANZANARES prototype during daytime. The comparison of calculated and measured SCPP without second roof output power is shown in Figure 5. The result power patterns were comparative and the pinnacle power was around 35kW at midday. Clearly, according to the Figure 5, our simulation results are in good agreement with the experimental.

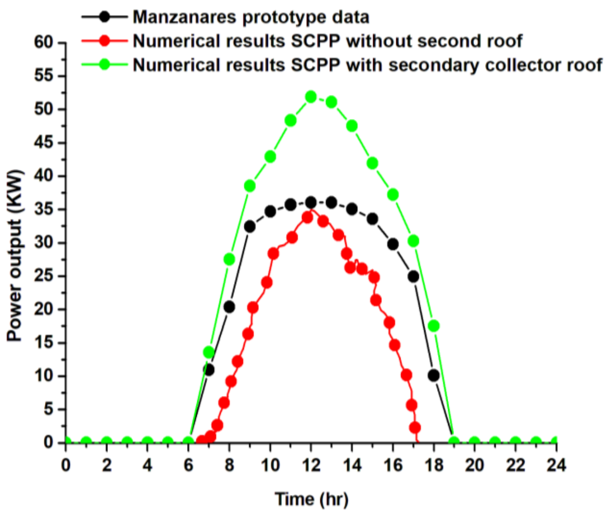

Fig. 5. Comparison of the power output between experimental data and numerical results

In Figure 6, the collector temperature of SCPP without second roof is compared with the measured data, it is observed that the trends of the two curves were similar to each other, but the temperature rise under the collector was quite different before 7 in the morning Finally we can say that the theoretical model proposed in this work can be considered as a reasonable model for the performance evaluation of a SCPP.

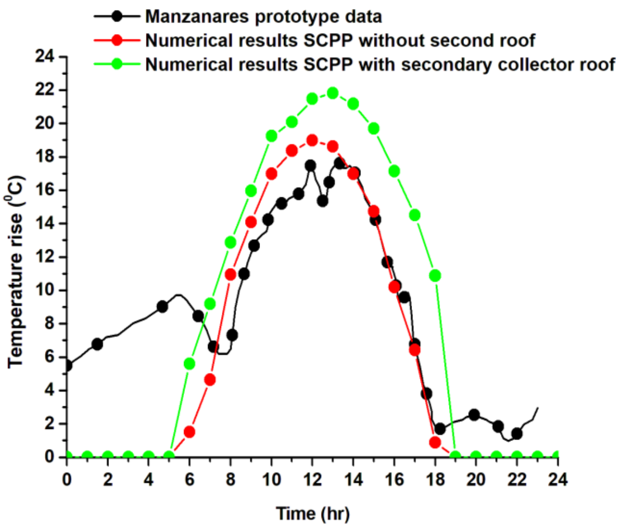

Fig. 6. Comparison of the temperature rise between experimental data and numerical results

3.2 Secondary Roof Effect

To analyze the effect of the secondary roof on the power output of the SCPP of MANZANARES, the power outputs without and with the inclusion of the secondary roof were calculated, at the solar irradiation of 800 W/m^2 and ambient temperature of 295 K. The height of the second roof is set (H = 0.75) m for SCPP with a second roof. The results showed that the output power is about 55 kW in the SCPP with the second roof collector and about 41.9 kW in the SCPP without second roof. The results indicate a power greater than 28.7% for the modified installation compared to the conventional SCPP (without second roof) as indicated in Table 2. It is evident that the power output of the facility increases with the inclusion of the secondary roof, the secondary roof gives the release energy from the additional collector, thus, in terms of production of peak electricity, it is clear that the inclusion of a secondary roof shows the significant power output potential of the SCPP.

Table 2
Power output comparison, illustrating the effect of incorporating a secondary collector roof

Type of chimney solar	Output power (kW)	Error relative
Conventional chimney solar	43.2	--
Chimney solar with second roof	55.6	28.7

Monthly variations in solar irradiation and ambient temperature at Sétif region of Algeria were collected from national project databases Yaiche *et al.,* [29]. The average monthly solar irradiation data on a horizontal surface (MJ/m^2. day) are shown in Figure 7. The global radiation curve has a similar bell shape and peaks during the month of June. These results were used to calculate the electrical power produced at Setif region. The solar chimney dimensions used in this calculus are based on the parameters of the Spanish prototype of MANZANARES.

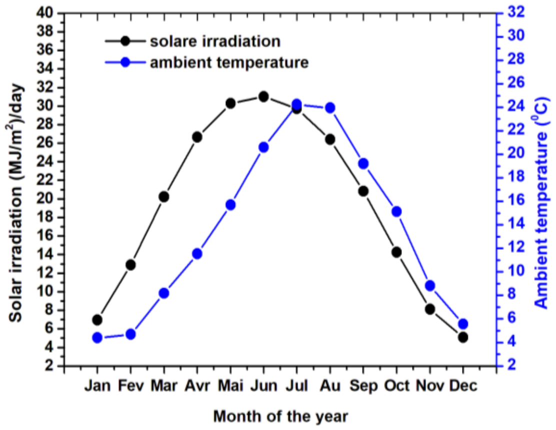

Fig. 7. Monthly solar radiation and ambient temperature at setif region

The annual electrical energy production of the conventional SCPP (without second roof) and of the SCPP with a secondary roof at Setif region is shown in Figure 8. The energy manufacturing of the traditional and the changed SCPP have the equal pace, they start to rise in January and reach their maximum values of 67.47 kW and 86.89 kW, respectively, in June. Then they go back down to zero at least in December. By producing a median annual cumulative electric power of 610.67 kW for the conventional SCPP and 782.60 kW for the modified SCPP. The trend observed can be linked to the variation in solar irradiation. In the case of the modified SCCP, it results in better electric energy generation than inside the conventional SCPP, the total power generated by the modified SCPP is 1.28 times larger than the maximum power generated by the conventional SCPP. It is noted that the energy production increases with the increase in radiation and ambient temperature. However, the solar irradiation is the dominant factor on the electricity production of the chimney solar power plant, compared to the ambient temperature.

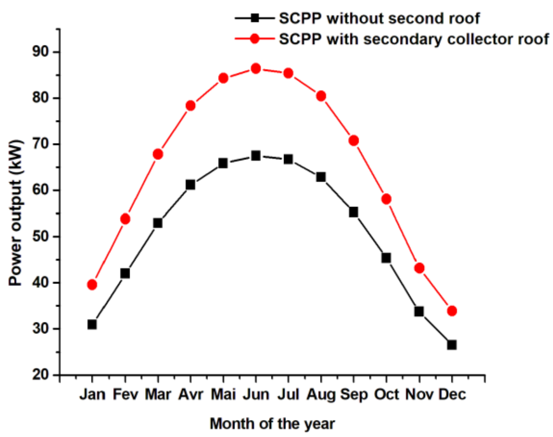

Fig. 8. Effect of incorporating a secondary collector roof on monthly average power productivity at Setif region

3.3 Effect of Secondary Roof Height

To analyze the effect of secondary roof height on output power, the power output of SCPP with secondary roof of different heights was calculated, at the solar irradiation of 800W/m^2 and ambient temperature 295 K. The solar chimney dimensions used in this calculus are based on the parameters of the Spanish prototype of MANZANARES. The effect of the height secondary roof on SCPP power output is shown in Figure 9. The results show that increasing the height of the second roof from 0.0 to 0.75 m leads to an increase in the power of the SCPP, and for a height over 0.75 m, the power of the SCPP decreases. Therefore, that there is an optimal height for the output power of SCPP to remain maximum. This leads us to say that the height of the secondary roof plays a very important role in the power output of the CSPP, because of its influence on the convective exchange coefficient between the two roofs.

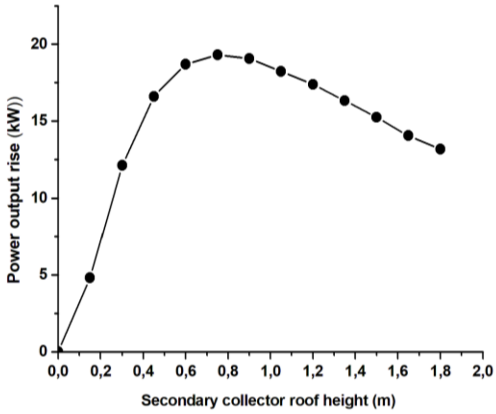

Fig. 9. Illustrating the effect of secondary collector roof length on power output

4. Conclusion

In this work, the influences of inclusion a second roof on the power output of CSPP have been studied by an analytical model, the analytical model presented in this work based on energy balance equations and mass conservation equation at steady state. In second step the proposed analytical model is then used to estimate the annual electricity production in Sétif, a region of Algeria. Following remarks might be achieved from the study

i. The output power of the installation increases with the inclusion of the secondary roof to 28.7 % compared to conventional SCPP.
ii. The results also show that increasing the height of the second roof from 0.0 to 0.75 m leads to an increase in the power of the SCPP, and for a height over 0.75 m, the power of the SCPP decreases. On the other hand, there is an optimal height for the output power of SCPP to remain maximal. This leads us to say that the height of the secondary roof plays a very important role in the power output of the CSPP, because of its influence on the convective exchange coefficient between the two roofs.
iii. It is noted that the energy production increases with the increase in radiation and ambient temperature. However, the solar irradiation is the dominant factor on the electricity production of the chimney solar power plant, compared to the ambient temperature.

References

[1] Schlaich, Jörg. *The solar chimney: electricity from the sun*. Edition Axel Menges, 1995.

[2] Ikhlef, Khaoula, İbrahim Üçgül, Salah Larbi, and Samir Ouchene. "Performance estimation of a solar chimney power plant (SCPP) in several regions of Turkey." *Journal of Thermal Engineering* 8, no. 2 (2021): 202-220.

[3] Abdelsalam, Emad, Feras Kafiah, Fares Almomani, Muhammad Tawalbeh, Sanad Kiswani, Asma Khasawneh, Dana Ibrahim, and Malek Alkasrawi. "An innovative design of a solar double-chimney power plant for electricity generation." *Energies* 14, no. 19 (2021): 6235. https://doi.org/10.3390/en14196235

[4] Choi, Young Jae, Dong Hoon Kam, Yoon Won Park, and Yong Hoon Jeong. "Development of analytical model for solar chimney power plant with and without water storage system." *Energy* 112 (2016): 200-207. https://doi.org/10.1016/j.energy.2016.06.023

[5] Larbi, Salah, Amor Bouhdjar, and Toufik Chergui. "Performance analysis of a solar chimney power plant in the southwestern region of Algeria." *Renewable and Sustainable Energy Reviews* 14, no. 1 (2010): 470-477. https://doi.org/10.1016/j.rser.2009.07.031

[6] Li, Jing-yin, Peng-hua Guo, and Yuan Wang. "Effects of collector radius and chimney height on power output of a solar chimney power plant with turbines." *Renewable Energy* 47 (2012): 21-28. https://doi.org/10.1016/j.renene.2012.03.018

[7] Choi, Young Jae, Yong Jin Kim, Sub Lee Song, and Younwon Park. "Development of a mathematical analysis model for solar updraft tower plant (SUTP) system." In *ISES Conference Proceedings*. 2015.

[8] Aissaoui, Faris, Abdelmoumene Hakim Benmachiche, Abdelhafid Brima, Derradji Bahloul, and Yousef Belloufi. "Experimental and theoretical analysis on thermal performance of the flat plate solar air collector." *International Journal of Heat and Technology* 34, no. 2 (2016): 213-220. https://doi.org/10.18280/ijht.340209

[9] Attig-Bahar, Faten, Melik Sahraoui, Mohamed Sadok Guellouz, and Slim Kaddeche. "Effect of the ground heat storage on solar chimney power plant performance in the South of Tunisia: Case of Tozeur." *Solar Energy* 193 (2019): 545-555. https://doi.org/10.1016/j.solener.2019.09.058

[10] Baral, Suresh. "Mathematical evaluation of sloped solar chimney power plant for power generation in different regions of Nepal." *International Journal of Low-Carbon Technologies* 16, no. 2 (2021): 620-627. https://doi.org/10.1093/ijlct/ctaa094

[11] Tayebi, Tahar, and Mahfoud Djezzar. "Effect of varying ambient temperature and solar radiation on the flow in a solar chimney collector." *International Journal of Smart Grid and Clean Energy* 5, no. 1 (2016): 16-23. https://doi.org/10.12720/sgce.5.1.16-23

[12] Ghalamchi, Mehran, Alibakhsh Kasaeian, Mohammad Hossein Ahmadi, and Mehrdad Ghalamchi. "Evolving ICA and HGAPSO algorithms for prediction of outlet temperatures of constructed solar chimney." *International Journal of Low-Carbon Technologies* 12, no. 2 (2017): 84-95. https://doi.org/10.1093/ijlct/ctw008

[13] Dai, Y. J., H. B. Huang, and R. Z. Wang. "Case study of solar chimney power plants in Northwestern regions of China." *Renewable Energy* 28, no. 8 (2003): 1295-1304. https://doi.org/10.1016/S0960-1481(02)00227-6

[14] Cuce, Erdem, Abhishek Saxena, Pinar Mert Cuce, Harun Sen, Shaopeng Guo, and K. Sudhakar. "Performance assessment of solar chimney power plants with the impacts of divergent and convergent chimney geometry." *International Journal of Low-Carbon Technologies* 16, no. 3 (2021): 704-714. https://doi.org/10.1093/ijlct/ctaa097

[15] Cuce, Erdem, Pinar Mert Cuce, Harun Sen, K. Sudhakar, Umberto Berardi, and Ugur Serencam. "Impacts of ground slope on main performance figures of solar chimney power plants: A comprehensive CFD research with experimental validation." *International Journal of Photoenergy* 2021 (2021). https://doi.org/10.1155/2021/6612222

[16] Kasaeian, Alibakhsh, Mehran Ghalamchi, and Mehrdad Ghalamchi. "Simulation and optimization of geometric parameters of a solar chimney in Tehran." *Energy Conversion and Management* 83 (2014): 28-34. https://doi.org/10.1016/j.enconman.2014.03.042

[17] Nasraoui, Haythem, Zied Driss, and Hedi Kchaou. "Effect of the chimney design on the thermal characteristics in solar chimney power plant." *Journal of Thermal Analysis and Calorimetry* 140, no. 6 (2020): 2721-2732. https://doi.org/10.1007/s10973-019-09037-3

[18] Hassan, Aakash, Majid Ali, and Adeel Waqas. "Numerical investigation on performance of solar chimney power plant by varying collector slope and chimney diverging angle." *Energy* 142 (2018): 411-425. https://doi.org/10.1016/j.energy.2017.10.047

[19] Too, J. H. Y., and C. S. N. Azwadi. "Numerical analysis for optimizing solar updraft tower design using computational fluid dynamics (CFD)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 22, no. 1 (2016): 8-36.

[20] Jawad, Ahmad, Mohd Suffian Misaran, Md. Mizanur Rahman, and Mohd Azlan Ismail. "Experimental Investigation on The Effect of Divergent Tower Solar Chimney on The Theoretical Power Potential." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 81, no. 1 (2021): 140-149. https://doi.org/10.37934/arfmts.81.1.140149

[21] Kinan, A., and N. A. Che Sidik. "Experimental studies on small scale of solar updraft power plant." *Journal of Advanced Research Design* 22, no. 1 (2016): 1-12.

[22] Saadun, Mohd Noor Asril, Nor Azwadi Che Sidik, and Masin Muhammadu. "Design and Optimizing of Geometric for Solar Updraft Tower using Computational Fluid Dynamics (CFD)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 51, no. 1 (2018): 8-18.

[23] Pasumarthi, N., and S. A. Sherif. "Experimental and theoretical performance of a demonstration solar chimney model-Part II: experimental and theoretical results and economic analysis." *International Journal of Energy Research* 22, no. 5 (1998): 443-461. https://doi.org/10.1002/(SICI)1099-114X(199804)22:5<443::AID-ER381>3.0.CO;2-V

[24] Bernardes, M. A. dos S., A. Voß, and G. Weinrebe. "Thermal and technical analyses of solar chimneys." *Solar Energy* 75, no. 6 (2003): 511-524. https://doi.org/10.1016/j.solener.2003.09.012

[25] Okoye, Chiemeka Onyeka, and Onur Taylan. "Performance analysis of a solar chimney power plant for rural areas in Nigeria." *Renewable Energy* 104 (2017): 96-108. https://doi.org/10.1016/j.renene.2016.12.004

[26] Schlaich, Jo¨ rg, Rudolf Bergermann, Wolfgang Schiel, and Gerhard Weinrebe. "Design of commercial solar updraft tower systems-utilization of solar induced convective flows for power generation." *Journal of Solar Energy Engineering* 127, no. 1 (2005): 117-124. https://doi.org/10.1115/1.1823493

[27] Nizetic, S., and B. Klarin. "A simplified analytical approach for evaluation of the optimal ratio of pressure drop across the turbine in solar chimney power plants." *Applied Energy* 87, no. 2 (2010): 587-591. https://doi.org/10.1016/j.apenergy.2009.05.019

[28] Haaf, W. "Solar chimneys: part II: preliminary test results from the Manzanares pilot plant." *International Journal of Sustainable Energy* 2, no. 2 (1984): 141-161. https://doi.org/10.1080/01425918408909921

[29] Yaiche, M. R., A. Bouhanik, S. M. A. Bekkouche, A. Malek, and T. Benouaz. "Revised solar maps of Algeria based on sunshine duration." *Energy Conversion and Management* 82 (2014): 114-123. https://doi.org/10.1016/j.enconman.2014.02.063