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Analysis and Validation of a Designed Solar Chimney with 50 KW Output Power between 7 AM and 5 PM during a Year as a Power Supply Unit for Bushehr Province, Iran

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Abstract

The aim of the current research is analysis and validation of a solar tower (chimney) designed for power generation in southern provinces of Iran, especially in Bushehr province. The analysis consists of preparing and drawing the graphs of solar irradiance intensity on horizontal planes, analysis of solar tower without storing, preparing graphs considering the diameter of collector (absorber or receiver), height of tower and diameter of turbine in 50 kW output power. Already, the amount of received solar energy is computed by available relationships governing on tower elements as a set of codes in MATLAB. In addition, experimental data is already used to validate the results obtained from finite element software FLUENT. In the current research, the obtained results from graphs produced by computer softwares (EXCEL and FLUENT) with 50 kW daily output power (from 7 AM to 5 PM during a year) are analyzed and validated comparing to the model produced in Manzanares, Spain. The obtained results are represented in two parts: the first one shows characteristic curve of solar towers (i.e. a curve representing the relationship between tower elements in a given power); the second part shows the variable output power during a day. It is obvious from characteristic curves that in low powers and small diameters, turbine needs large size receiver and high equivalent height. Considering the cost effectiveness conditions, it can scientifically compete with the produced model.

Keywords: Bushehr province; Analysis and validation; Solar tower (chimney); Solar turbine; MATLAB; Solar collector (receiver); Characteristic curves; EXCEL and FLUENT softwares.

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1. Introduction

Economic assessments based on the collected information and previous experiments have been shown that large solar towers (higher than 100 MW) have power generation capacity with costs comparable to traditional power plants (Badenwerk and EVS, 1997). This fact can be a reasonable reason for developing this type of solar energy consumption in large scale and establishing applicable sections from economic point of view. In the future energy economy, solar towers can be safe (from environmental point of view) and economic electricity generation method for sunny regions. Three main components of initial plan of a solar tower – solar collector, chimney or tower and wind turbines – are constant for many years. Their combination for power generation was described in 1931. Haaf (1983, 1984) represented the results of experiments and the theory of first solar tower in Manzanares, Spain [11,12]. The obtained results in Manzanares discussed by Schlaich (1990). In 1995, he reviewed this process. In 1997, Kreeetz introduced the concept of updraft water tubes beneath the collector ceiling for heat storing [1,10,13,14]. Gannon and Backstrom represented the analysis of thermodynamic cycle of solar tower and an analysis of turbine characteristics in 2000 and 2003, respectively. In 2003, Ruprecht reported the results of fluid dynamic analysis and turbine plan for a 200 MW solar tower. Currently, a 200 MW solar tower project is under construction in Australia by a German company under supervision of Prof. Jorg Schlaich that will be completed in 2010. The appropriate weather conditions in Australia for such type of solar power plant, very high isolation planes, plenty of straight lands, high demands for electricity and the presence of Mandatory Renewable Energy Target (MRET) will lead to 9500 GWh power generation between 2010 to 2020 [1,14]. Here, two cases of solar analysis are described:

- Solar tower analysis without storing
- Modelling the problem as a characteristic curve by a software

2. Solar tower analysis without storing

In the current paper, the geographical position of Bushehr province is firstly assessed to determine the amount of irradiation energy and the related experimental relationships for obtaining the irradiation intensity in various months of the year. After assessment of solar irradiation intensity in various months of the year (that is the supply source of energy), energy chain equations are considered for various parts of the plan including collector, glass cover, air between collector and glass cover and then, momentum equation for velocity analysis in the tower and the governing equations on the turbine are considered for obtaining 50 kW output power. Through simultaneous solving the above equations, the desired parameters of the problem such as temperature entered to solar tower, diameter of collector, height of tower, air velocity entered to the turbine and diameter of turbine can be obtained. In order to continuing the operation of solar tower over the night, updraft water tubes with sizes obtained from the mentioned equations are used. After analyzing the previous design steps such as determining the size of various parts of plan, economic comparability of the plan is controlled with the model produced in Manzanares, Spain [1,14]. The aims of the plan are including: 1. Evaluation of geographical position of Bushehr province to determine the amount of received solar irradiance energy 2. Obtaining the solar irradiance intensity in various months of the year in Bushehr province 3. Analyzing momentum energy chain equations for various parts of the plan in order to generate 50 kW power 4. Software analyses of the equations in order to determine:

a) collector size, temperature entered to the turbine b) height of solar tower c) Kaplan turbine size 5. Economic justification of the plan compared to power generated in the model produced in Manzanares, Spain. Figure (1) shows the schematic view of the designed solar tower and its elements in R-Z coordinate:

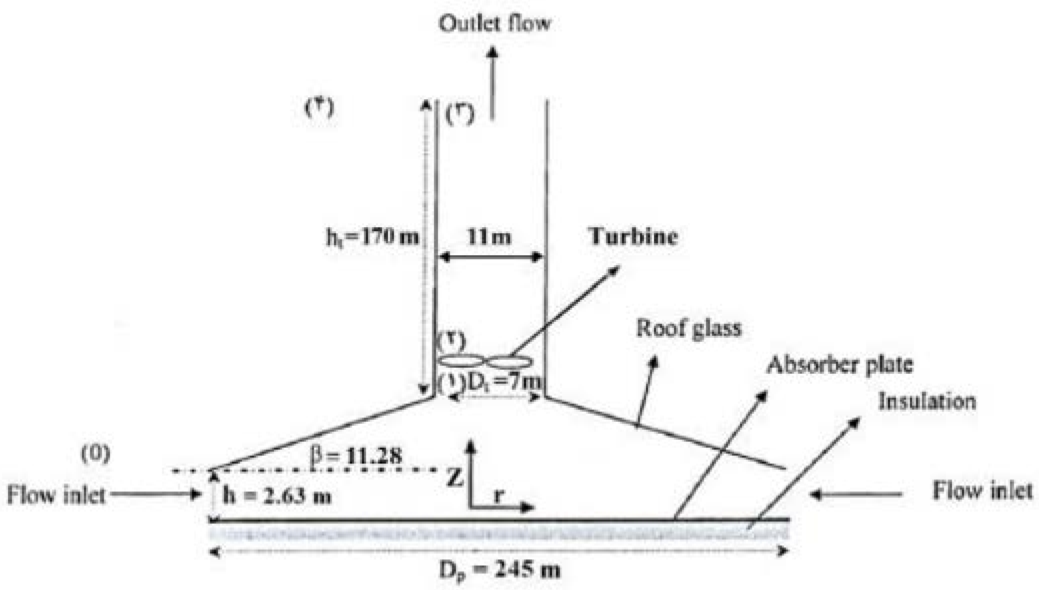

Figure 1: Schematic view of the designed solar tower and its elements in R-Z coordinate [1, 6, 10, 19]

3. General governing equations for determining output values [1, 5, 7, 8, 14, 15]

3.1. Calculation of collector values

1. General transformation equations

$$\mathrm{Div}(p\varphi\bar{U}) = \mathrm{div}\ (\eta \mathrm{grad}\varphi) + s_{\varphi} \quad (1\text{-}1)$$

$$\vec{u} = v_r\ \ \vec{e_r} + v_z\ \ \vec{e_z} \quad (1\text{-}2)$$

2. Energy equation obtained from Gauss divergence theory: $\mathrm{d}v\ \int_A \mathrm{n}.(\rho\ \phi\ \mathrm{u})\mathrm{dA} = \int_A \mathrm{n}(\ \eta\ \mathrm{grand}\ \phi\ )\ \mathrm{dA} + \int_{\mathrm{c.v}} s_{\varphi}$

3. Determining angle δ: $\delta = 23.4\sin\frac{360\mathrm{n}}{365}$

4. Irradiance values for days in a year outside of the atmosphere:

$$G_{on} = G_{sc}\left[1 + 0.033\cos\left(\frac{360\ (n+81)}{365}\right)\right] \quad (1\text{-}4)$$

$$G_{on} = G_{sc}\left[1 + 0.033Cos\ \left(\frac{360(n+81)}{365}\right)\right] \times [Sin\delta\ .Sin\varphi + Cos\delta\ .Cos\varphi\ Cos\omega] \quad (2\text{-}4)$$

5. Ratio of direct radiation on an inclined plane relative to horizontal plane: $R_b = \frac{G_{bt}}{G_{bh}} = \frac{G_{bn}Cos\theta}{G_{bn}Cos\theta_z} = \frac{Cos\theta}{Cos\theta_z}$

6. Determining the amount of scattered radiation:

$$\frac{I_d}{I_h} = 1 - 0.249\ K_T \quad \text{for } K_T < 0.35 \qquad (1\text{-}6)$$

$$\frac{I_d}{I_h} = 1.557 - 1.84\ K_T \quad \text{for } 0.35 < K_T < 0.75 \qquad (2\text{-}6)$$

7. Determining direct radiation: $I_b = I_h - I_d$

8. Amount of radiation on inclined plane: $I_T = I_b R_b + I_d (I + Cos\beta) /2 + \rho_g(I_b + I_d) (1 - Cos\beta)/2$

9. Determining solar hour:

$$\text{Solar time} - \text{Local time} = 4(L_{st} - L_{loc}) + E \qquad (1\text{-}9)$$

$$E = 9.87\ Sin\ 2\beta - 7.23\ Cos\beta - 1.5\ Sin\beta\ ,\ \beta = \frac{360n}{364} \qquad (2\text{-}9)$$

10. Density and environmental specific heat capacity in the entrance of the tower between 300 and 350 Kelvin:

$$\rho = 1.1614 - 0.00353(T - 300) \qquad (1\text{-}10)$$

$$C_\rho = \left(1.007 + 0.00004(T - 300)\right).10^3 \qquad (2\text{-}10)$$

11. Heat transfer coefficients on the flux between plastic cover and air and or absorber plane and air:

$$Nu_x = \frac{1}{\sqrt{\pi}} \sqrt{Re_x} \frac{p_r}{(1+1.7p_r^{\frac{1}{4}} + 21.36p_r)^{\frac{1}{6}}} \quad Re \prec 5 \times 10^5 \qquad (1\text{-}11)$$

$$Nu_{ave} = 2Nu_x \quad \text{baehr and Stephan} \quad (1996) \qquad (2\text{-}11)$$

$$Nu_m = \frac{0.037\ Re^{0.8}\ pr}{(1+2.443\ Re^{-0.1}(pr^{\frac{2}{3}}-1)} \quad 5 \times 10^5 \prec Re \prec 10^7 \qquad (3\text{-}11)$$

$$0.6 \prec pr \prec 200 \quad \text{petukhov and popov (1963)} \qquad (4\text{-}11)$$

$$Nu_m = \sqrt{Nu^2\ m, lam + Nu^2\ m, tur} \quad \text{Schlichting (1999)} \qquad (5\text{-}11)$$

12. Determining the velocity and flow rate of collector:

$$V_n = \frac{2\pi}{3}(R_{n+1}^3 - R_n^3) \qquad (1\text{-}12)$$

$$Q = \int_A u\, dA \;\; or \;\; Q = \frac{V\pi D^2}{4} \;,\; V = \frac{Q}{A} \;\; or \;\; V = \frac{4Q}{\pi D^2} \qquad (2\text{-}12)$$

13. Heat flux absorbed by earth:

$$\frac{Q}{A} = [I.\tau_2 + I.\tau_2.\rho_1\rho_2 + \alpha I.\tau_2.\rho_1^2\rho_2^2 + \ldots]\alpha_1 = I.\tau_2\alpha_1 \sum_{n=0}^{\infty}[\rho_1\rho_2]^n = \frac{I.\tau_2\alpha_1}{1-\rho_1\rho_2}$$

14. Determining the radius, area and perimeter of collector:

$$R_{n+1}^3 = (\frac{3\pi}{2}V_n + R_n^3)^{\frac{1}{3}} \qquad (1\text{-}14)$$

$$dA = 2\,\pi\, R\, dr \;\;,\;\; dr \in dx, dy, dz \qquad (2\text{-}14)$$

$$S = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \qquad (3\text{-}14)$$

15. Conductive heat transfer coefficient between two planes (bottom of collector and cover ceiling): $K = \frac{2}{\pi d_f}\frac{\rho_\omega}{\rho_f}$

16. Radiative heat transfer coefficient between two planes (bottom of collector and cover ceiling): $h_r = \frac{\sigma(T_p^2 + T_g^2)(T_p + T_g)}{(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_g} - 1)}$

17. Heat transfer coefficient between two planes:

$$q = \frac{T_{inside} - T_{amb}}{R_{tot}} = UA\,(T_{inside} - T_{amb}) \qquad (1\text{-}17)$$

$$q''_{flat} = \frac{\sigma(T_p^4 - T_g^4)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_g} - 1 + \sum_{n=1}^{N}(\varepsilon_{np} + \varepsilon_{ng} - 1)} \qquad (2\text{-}17)$$

$$q''_{cyl} = \frac{\sigma(T_p^4 - T_g^4)}{\frac{1}{\varepsilon_p} + (\frac{A_p}{A_g})(\frac{1}{\varepsilon_g} - 1) + \sum_{n=1}^{N}(\frac{A_p}{A_{sng}})(\frac{1}{\varepsilon_{np}} + \frac{1}{\varepsilon_{ng}} - 1)} \qquad (3\text{-}17)$$

18. Temperature entered to the chimney: $T(0) = T_{\infty inlet} + \frac{\pi G \eta_{coll}}{c_p \dot{m}} R_{coll}^2$

3-2- Calculation of turbine values

19. Determining turbine specific velocity: $\omega_s = \frac{\omega\sqrt{p}}{\rho^{\frac{1}{2}}\,(gH_T)^{\frac{5}{4}}}$

20. Determining turbine diameter: $D_s = \frac{D\,(gH_T)^{\frac{1}{4}}}{\sqrt{\varphi}}$

21. Determining energy difference between two heads of turbine: $H_T = \frac{\Delta p_{\text{Loss turbine}}}{\gamma}$

22. Determining pressure lose and efficiency of turbine: $\Delta p_{\text{Loss turbine}} = \frac{p}{Q\eta}$

3-3- Calculation of tower values

23. Tower energy equation using pressure lose between two heads of turbine: $\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + H_T = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2$

24: Total and static pressure equation: $P_0 = P_s + {}^1\!/_2\, \rho V^2$

25. Determining tower height and energy after turbine:

$$H_L = \frac{V_3^2}{2g} \quad (1\text{-}25)$$

$$H_l = \frac{p_0 - p_4}{\gamma} + Z_1 - Z_4 - \left(\frac{\Delta p_{\text{Loss chimeny}}}{\gamma} + \frac{\Delta p_{\text{Loss turbine}}}{\gamma}\right) \quad (2\text{-}25)$$

26. Determining tower diameter considering the friction:

27. Laminar flow: $Re < 2100$, $f = \frac{16}{Re}$

28. Turbulence and smooth flow:

$$4000 < Re < 10^7 \;,\; \frac{1}{\sqrt{f}} = 1.5635\ln\left(\frac{Re}{7}\right) \quad (1\text{-}28)$$

$$\left\{\frac{1}{\left[\left(\frac{8}{Re}\right)^{10} + \left(\frac{Re}{36500}\right)^{20}\right]^{\frac{1}{2}}} + 2.2\ln\frac{Re^{10}}{7}\right\}^{\frac{1}{5}} \quad (2\text{-}28)$$

29. Turbulence and rough: $10^{-6} < e/1 < 10^{-2}$ $\frac{\Delta p_{\text{Loss chimeny}}}{\gamma} = \frac{f H V^2}{2gD}$,

30. Determining the ultimate velocity and density inside the chimney until the end of chimney pipe:

$$V = \sqrt{\frac{2}{\rho}\int_0^H (p_a - p) g.\, dH - \left[\,(\Delta p_{\text{Loss chimeny}} + \Delta p_{\text{Loss turbine}})\right]} \quad (1\text{-}30)$$

$$(z) = \rho\,(0)\,\left(1 + \frac{k-1}{k}\,\frac{z}{\frac{RT}{g}}\right)^{\frac{1}{k-1}} \rho \quad (2\text{-}30)$$

Table (1) shows the real size and technical properties of initial model compared to the model produced in Manzanares, Spain:

Table 1: The real size and technical properties of initial model compared to the model produced in Manzanares, Spain

characteristics	Manzanares, Spain	Bushehr, Iran
tower height:	194.6 m	196 m
tower radius:	5.08 m	5.5 m
mean collector radius:	122.0 m	122.5 m
roof height:	1.85 m	2.63 m
number of turbine blades:	4	7
turbine blade profile:	FX W-151-A	FX W-151-A
blade tip speed to air transport velocity ratio:	1 : 10	1.57 : 11
operation modes:	stand-alone or grid connected mode	stand-alone or grid connected mode
typical collector air temp. increase:	ΔT = 15 C	ΔT = 15 C
nominal output:	50 kW	50 kW
coll. covered with plastic membrane:	40'000 m²	48'000 m²
coll. covered with glass:	6'000 m²	7200 m²

4. Modelling the problem as a characteristic curve by a software

4.1. Graph of solar irradiance intensity on a horizontal plane in Bushehr province, Iran [1]

For Bushehr province with latitude Φ = 28.5, in 15th day of each month, solar irradiance on a horizontal plane in Figures (2) to (13) which is considered in the plan, is calculated:

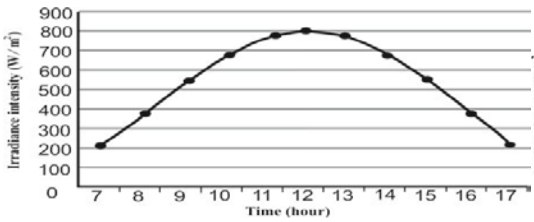

Figure 3: Irradiance intensity on the 15th Ordibehesht (5th may)

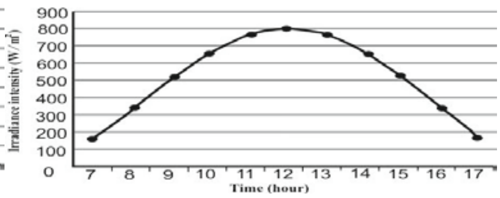

Figure 2: Irradiance intensity on the 15th Farvardin (4th April**)**

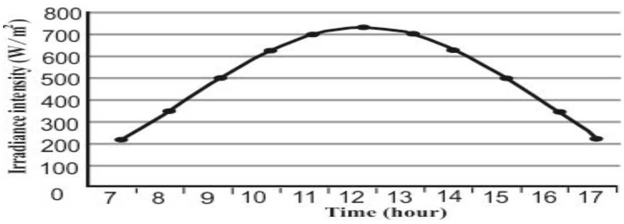

Figure 4: Irradiance intensity on the 15th Khordad (5th June)

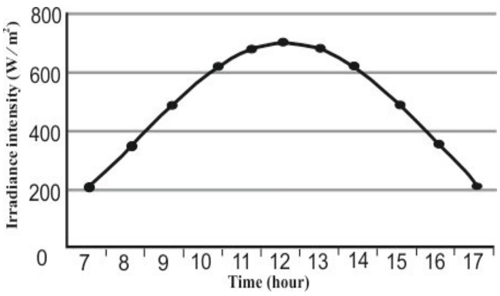

Figure 5: Irradiance intensity on

the 15^{th} Tir (6^{th} July)

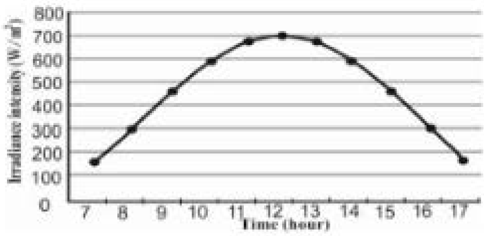

Figure 7: Irradiance intensity on

the 15^{th} Shahrivar (6^{th} September)

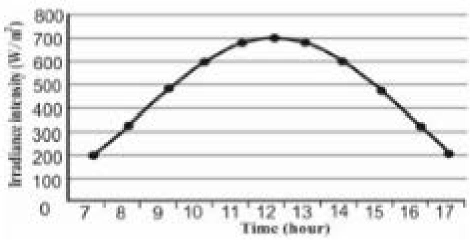

Figure 6: Irradiance intensity on

the 15^{th} Mordad (6^{th} August)

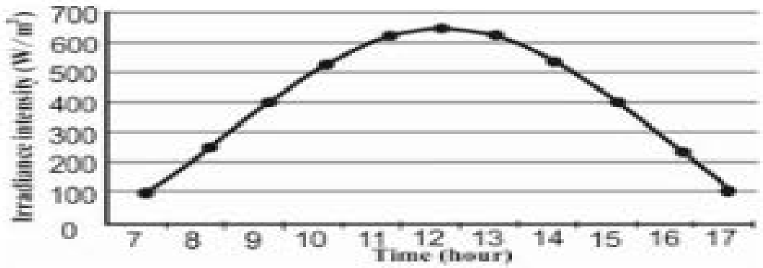

Figure 8: Irradiance intensity on the 15th mehr (7th October)

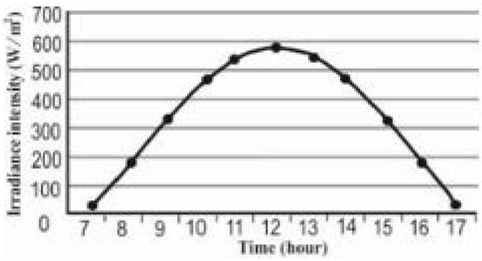

Figure 9: Irradiance intensity on the 15th Aban (6th November)

Figure 11: Irradiance intensity on

the 15th Dey (5th Janury)

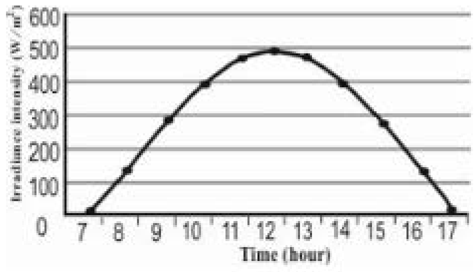

Figure 10: Irradiance intensity on

the 15th Azar (6th December)

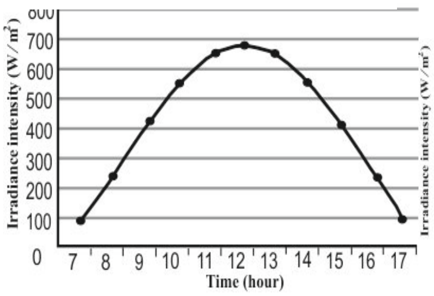

Figure 13: Irradiance intensity on

the 15th Esfand (6th March)

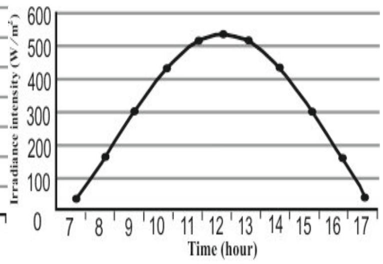

Figure 12: Irradiance intensity on

the 15th Bahman (4th February)

Figures 2: to (13) – Graphs of solar irradiance intensity on a horizontal plane on the considered plan during a year in Bushehr province [1]

4.2. Results

In this section, results are presented and discussed. This section is divided into two general subsection; the first one is about the results and their discussion and the second one is about the confirmation of the obtained results. The first subsection consists of two parts; the first one is related to representing characteristic curves of solar tower in various output powers which shows the relationship between diameter of collector, diameter of turbine and height of tower in a given output power. In the second one, using the graphs of first part, the size of solar tower for generating 50 kW power from 7 AM until 5 PM in 12 months of a year is calculated. Due to variation of solar irradiance intensity in various hours of various months, output power graph is a function of hour on day on a month and hence, the corresponding graphs for 15th day of each month is represented here.

4.3. Results and discussion

4.3.1. Characteristic curves of solar tower

Here, the characteristic curves of solar tower are represented. Using these curves, it is possible to determine the relationship between three main factors in solar towers including diameter of collector, tower height and diameter of turbine in any given output power. These curves are the basis for optimizing the cost of solar tower manufacturing in a given output power. The characteristic curves of solar towers in the case of using updraft water tubes are sown in Appendix C [1]. Figures (14) to (17) the characteristic curves of a solar tower are calculated at the power of 50, 200 kW and 1 and 10 MW, which is considered in the plan:

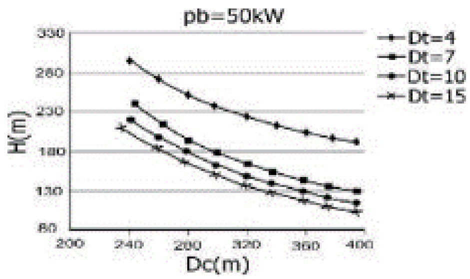

Figure 14: Characteristic curve of solar tower for 50 kW power

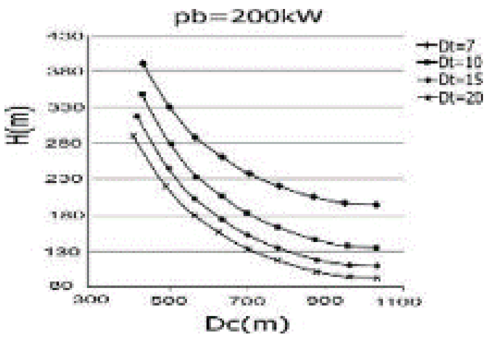

Figure 15: Characteristic curve of solar tower for 200 kW power

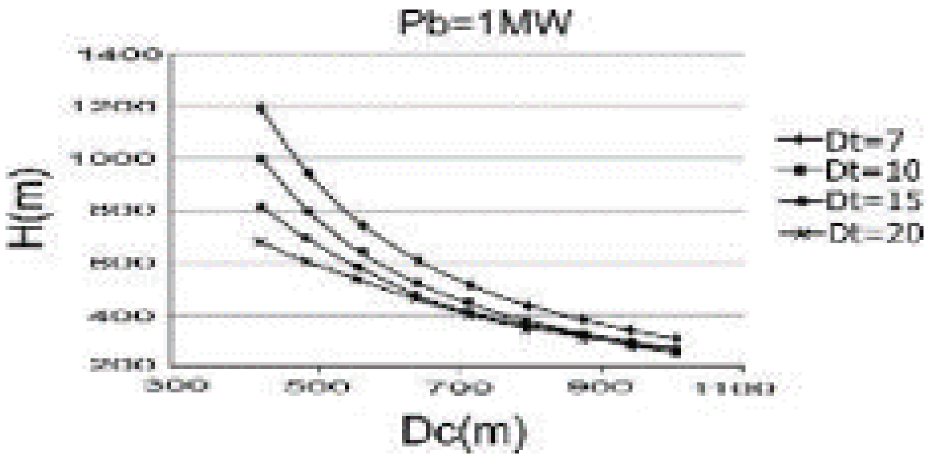

Figure 16: Characteristic curve of solar tower for 1 MW power

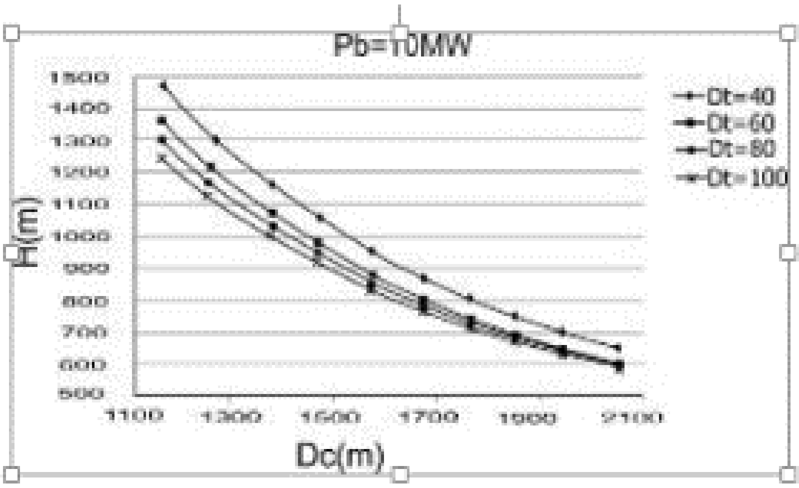

Figure 17: Characteristic curve of solar tower for 10 MW power

4.3.2. Variable output power for various months of the year

Here, the output power of solar tower for diameter of turbine 7 m, tower height 196 m, diameter of collector 245 m and inner diameter of chimney 11 m are represented for various months of the year [1].

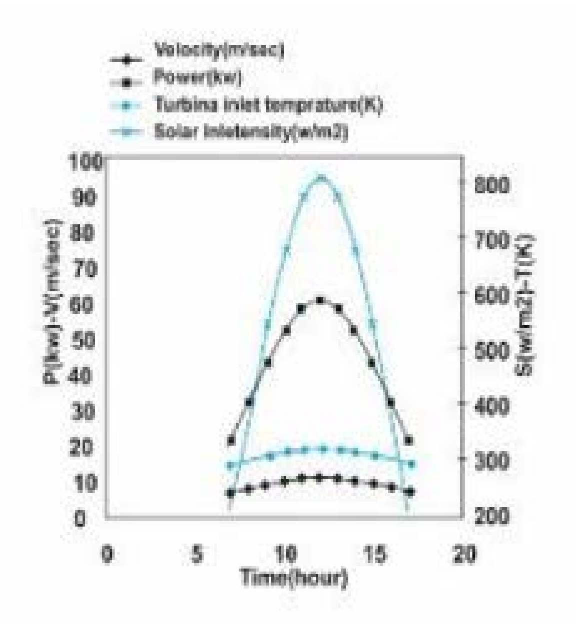

Figure 19: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Ordibehesht (May)

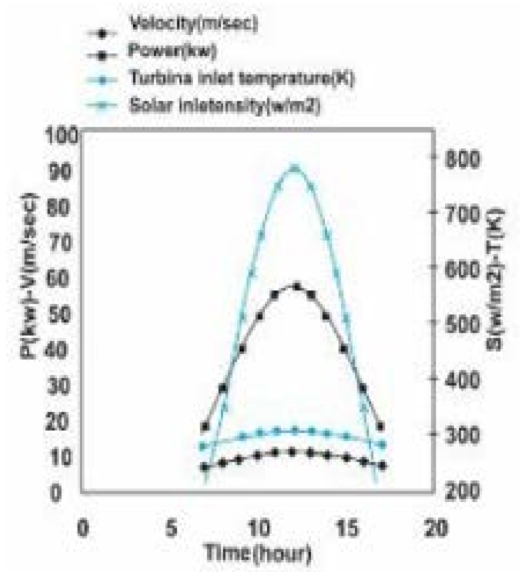

Figure 18: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Farvardin (April)

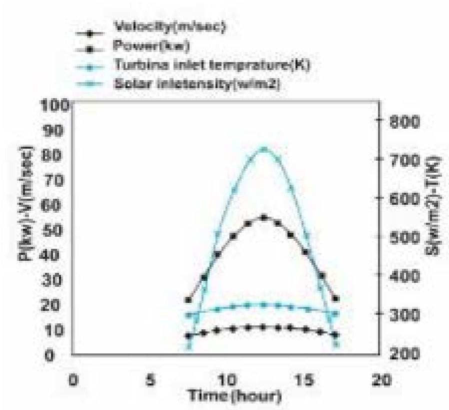

Figure 23: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Shahrivar ((September)

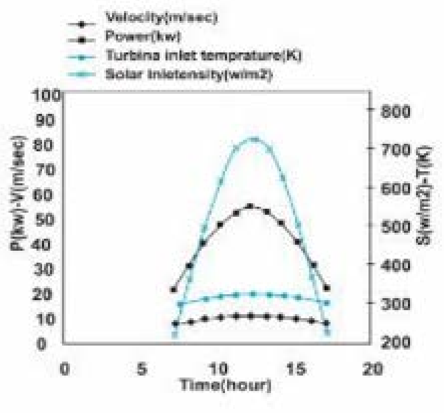

Figure 22: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 (PM in Mordad (August)

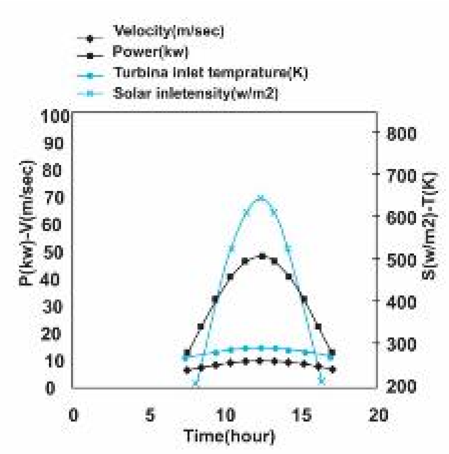

Figure 25: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Aban (November)

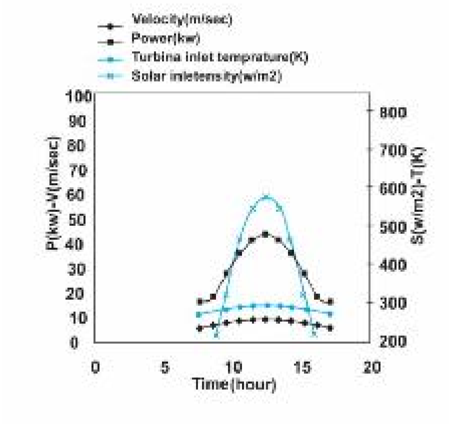

Figure 24: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Mehr (October)

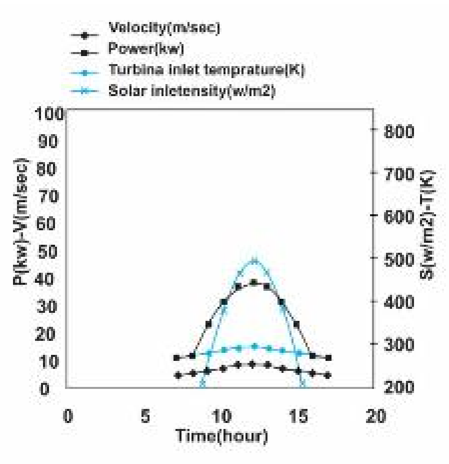

Figure 27: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Dey (January)

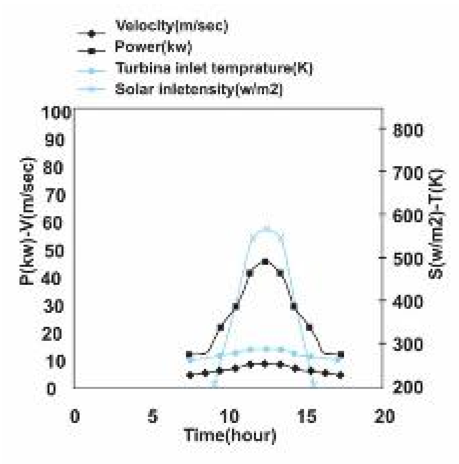

Figure 26: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Azar (December)

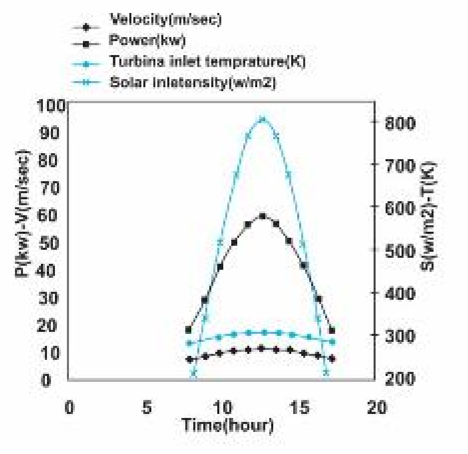

Figure 29: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Esfand (March)

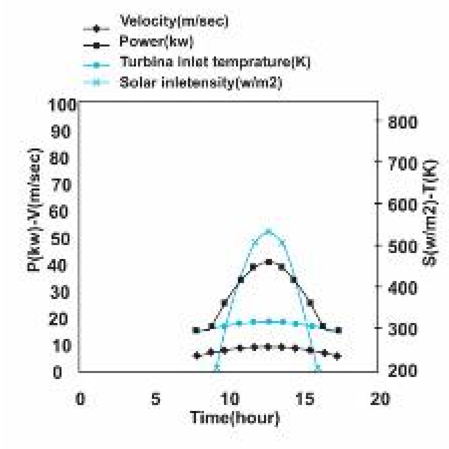

Figure 28: Power, irradiance intensity, temperature and exit velocity from 7 AM until 5 PM in Bahman (February)

4.3.3. Confirmation of results and suggesting a computer analysis model

Here, the results obtained from analytical solution, computer solution and experimental solution are compared. To analyze the problem, the given geometry is inputted into FLUENT software and solved with finite volume method. In all steps of solution, a set of equations is resulted which is solved with Gauss – Seidel elimination method using LU decomposition [1,14,16,17]. For example, on 12 AM, Esfand, the average velocity obtained from analytical solution is 1205 m/s while computer model gives this value as 15.5 m/s and experimental model leads to 10m/s [1,14,18,20]. This difference is due to following facts:

1- In analytical and computer models, absorber planes are considered as black metal plane while in the model produced in Manzanares, Spain, earth was directly used as absorber plane and hence, more heat was absorbed in a low velocity.

2- The environmental conditions of Bushehr is different from Manzanares, Spain. The following graph shows the variations of velocity from center of the tower to its wall based on the results obtained from FLUENT.

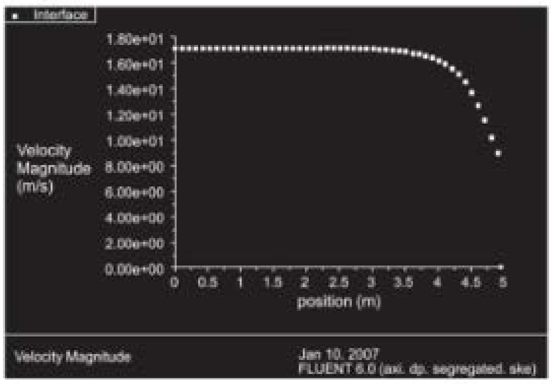

Figure 30: Variations of velocity from center of the tower to its wall in 12 AM, 15th Esfand (6th March)

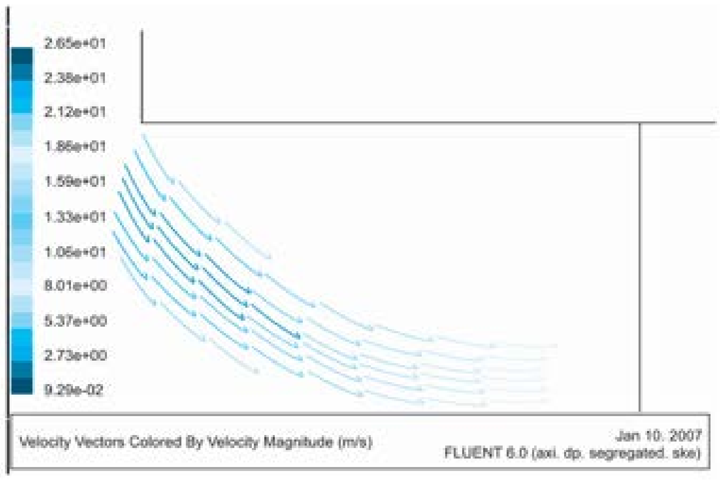

Figure 31: Flow lines inputted to the turbine

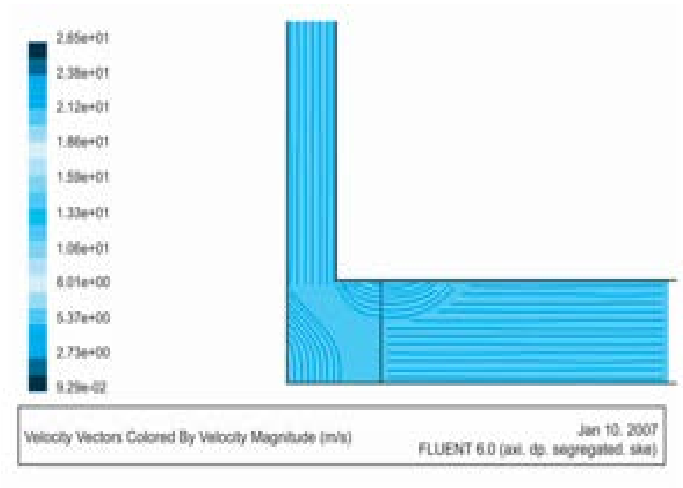

Figure 32: Constant velocity lines from the collector to the turbine and finally the tower

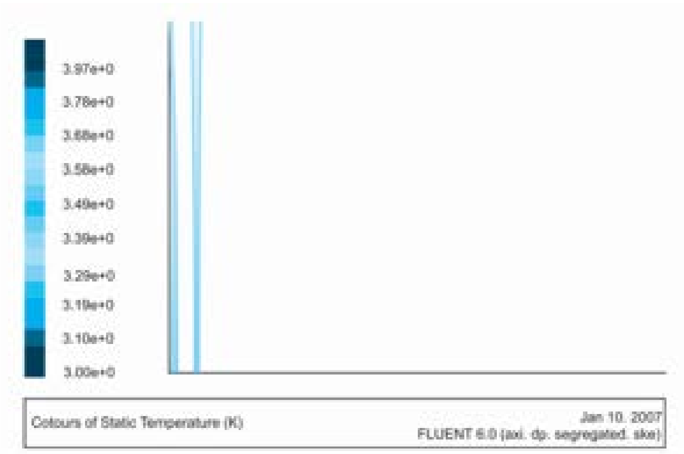

Figure 33: Constant temperature lines along the tower

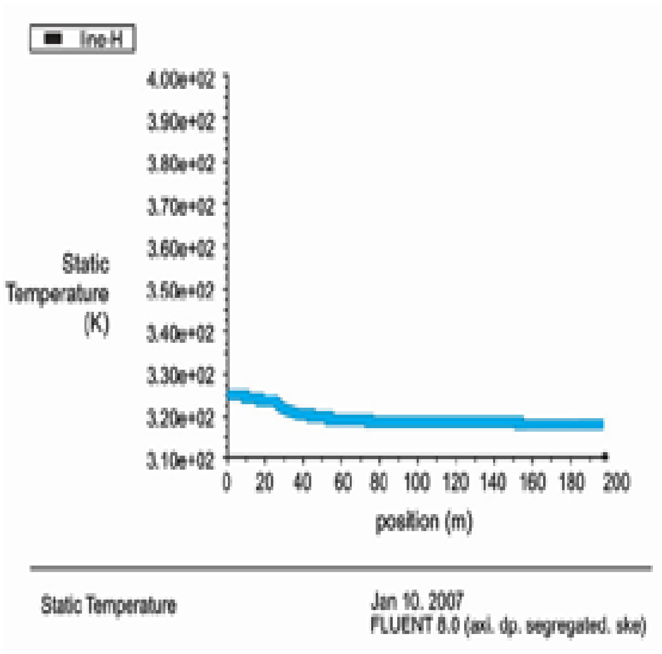

Figure 34: Variations of temperature along the tower in terms of position

The following graphs show the variations of output power, enter velocity to the turbine and irradiance intensity in the model produced in Manzanares, Spain, recorded by measuring devices, compared to calculated values for a model with the same size in Bushehr [1,14].

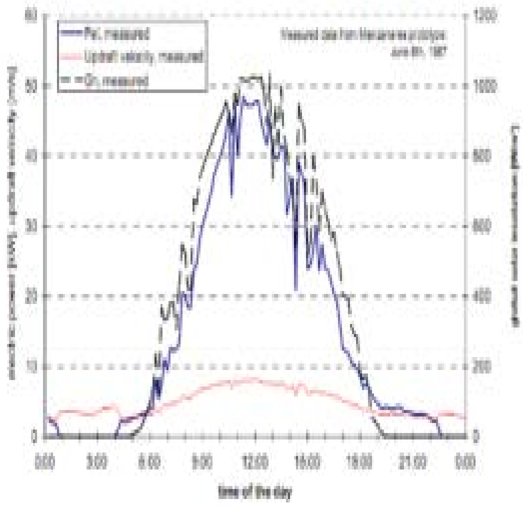

Figure 35: Variations of output power, entrance velocity to the turbine and irradiance intensity in the model produced in Manzanares, Spain (8th June)

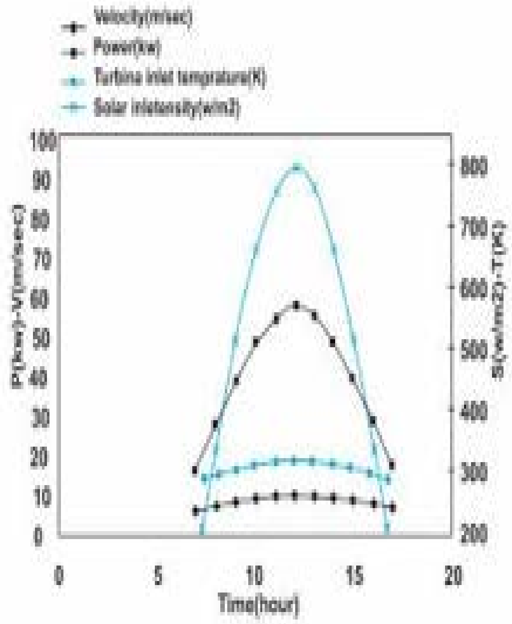

Figure 36: Average power, irradiance intensity, temperature and exit velocity at best comparison case between 7 AM and 5 PM, from 15th Esfand (6th March) to 15th Ordibehesht (5th May), Bushehr, Iran

4. Conclusion

Regarding the point that Iran is located between 25-45 north latitude and Bushehr province is located on Φ = 28.5, this region is one of the best regions in the world for receiving solar energy. In addition, huge investment is necessary for successful generation of power from solar energy. Therefore, the success of power generation from solar energy is related to easy and cheap manufacturing of collector, which is the most expensive parts of power generation process from solar energy. As a result, considering the order of equation solving, characteristic curves of solar tower are drawn using the size of designed solar tower for diameter of turbine 7 m (seven turbines with 1 m diameter), tower height 196 m, and diameter and ceiling height of collector 245 m and 2.63 m, respectively, compared to the model produced in Manzanares, Spain. At 12 AM, Esfand, the average velocity obtained from analytical solution is 12.5 m/s while this is 15.5 and 10 m/s for computer solution and experimental solution, respectively. The relationship between collector diameter, turbine diameter and tower height is drawn for 50 kW output power so that the proposed model can be verified through it. Further, due to variation of solar irradiance intensity from 7 AM until 5 PM during a year, and hence, variation of irradiance on smooth plane, the values of output power, temperature and average wind velocity entered to the turbine in Bushehr is obtained, compare to Manzanares, Spain, as 1012-788 W/m^2, 50-50 kW, 288-288 º k, and 10-12.5 m/s, respectively. These results indicate that irradiance values on smooth plane, temperature, average wind velocity entered to the turbine and output power of solar tower are dependent on the considered time during the year. This problem can be solved through experimental data and the results of characteristic curves obtained from FLUENT software as the basis for optimum analysis of size and output power of a solar tower towards the generation of required energy in terms of weather conditions of Bushehr province.

5. Nomenclature [1,14,20,21]

Table 2

direct irradiance on inclined plane	G_{bh}	Unit volume	ν
Inclined angle	δ	density	ρ
Departure angle of plane	γ	Refraction coefficient	ρ_g
Departure angle of sun	γ_s	pressure	P
Irradiance angle	θ	Coefficient of kinematic viscosity	μ
Zenith angle	θ_z	Gravitational acceleration	g
Hour angle	ω	Reference density	ρ_0
Ratio of direct irradiance on inclined plane to horizontal plane	R_b	Heat conductivity coefficient (Eq. 4)	β
Standard longitude	L_{st}	Angle of plane to horizontal plane (Eq. 11)	β
Local longitude	L_{loc}	Inner air temperature in entrance of tower	T
Time equation in terms of minute	E	Reference temperature	T_0
Received irradiance directly on horizontal plane	I_b	Outside air temperature in origin	T_a
Received irradiance refracted on horizontal plane	I_d	Specific heat coefficient in constant pressure	C_p
Received irradiance on horizontal plane	I_h	Conductive heat transfer coefficient	K
irradiance on inclined plane	I_T	Air non-cloudiness coefficient	K_T
radiative heat transfer coefficient	h_r	Flow function	ϕ
Convective heat transfer coefficient	h_c	Angle on spherical or cylindrical coordination system	φ
Boltzmann constant	σ	Refraction coefficient	η
Refraction coefficient	ε	Normal unit vector (Eq. 8)	n
Power of turbine	H_r	Day definition in the year (Eq. 9)	n
Pressure lose due to friction	Δp_{loss}	Irradiance intensity in terms of days of the year	G_{on}
Output power of solar tower	p_b	Average irradiance intensity	G_{sc}
Characteristic diameter of turbine	D_s	Direct irradiance on horizontal plane	G_{bt}

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