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Effect of Designing Parameters and Weather Conditions on the Operation of SCPP in Baghdad

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Abstract— *Under this title with using Matlab software program. The current work aims to analyze, describe and indicate the extent of variables influence on the design and work of the solar chimney to produce electric energy. A model has been developed that represents a design that suits the conditions of the city of Baghdad. Geographic coordinates of Baghdad-Iraq are (Latitude: 33°20'26" N, Longitude: 44°24'03" E, Elevation above sea level: 41 m = 134 ft), this coordinate tells us that Iraq is located above the equator. Various conditions have also been chosen to identify the performance characteristics and work of solar chimneys, taking into consideration the change of important parameters for the design of the solar chimney. The tests are based on working conditions that simulate the default system represented for real-time work. Parameters have been assumed in the program to see the effect of changing these parameters on performance and design (volume flow rate, mass flow rate, efficiency and ACH) for solar chimneys such as d, z, Ls and temperature According to the Baghdad city season (summer = 500, spring = 300, winter = 100). The results showed that the volume flow rate increases about 60% when Ls is double. The overall flow rate increases by about 62% when the Ls increase from 10 to 20. The efficiency increases by about 7% when the Ls are double. When Ls increases twice the ACH increase 60% the ACH increases when H increases.*

Keywords— *Solar chimney, Energy balance, Gauss-Seidel, Volume flow rate, Mass flow rate, Efficiency and ACH.*

I. INTRODUCTION

There are many ways to electricity generated like solar, wind [1-3]. The stations are built from the solar thermal type, which is called (solar chimney), to generate electricity [4-6]. The solar chimney has three main parts (chimney, solar collector and turbine) [7-9]. This type contains a tower located in the center of the chimney. In addition to the presence of a solar air collector. There is also a turbocharged base in its base. It relies on its work on solar radiation, which heats the air and raises the temperature at the outlet of the complex [10-12]. Physically, vitality is the quantitative property that must be exchanged to a body in arrange to perform work on the body or warm it. Energy is a preserved amount, the energy conservation law states that energy can be transferred from one form to another, but not created or vanished. The power unit SI is the Joule, which is the energy projected onto an object to move it for 1 meter against a force of 1 Newton [13-15]. There are several forms of energy, the most common of which are the kinetic energy of a moving object, the potential energy stored by the location of the body in the force field (gravity, electric or magnetic), the chemical energy released when the fuel is burned and the radiant energy carried by light and energy Thermal due to body temperature [16-18]. Kinetic energy, Potential energy, Thermal and radiant energy are important in modelling solar chimneys energy balance equation to explain the work and principle of operation [19-21]. Energy balance can be defined simply as the difference between input energy and output energy, the formula: [ENERGY=POWER×TIME (Joule)].

The matter is show around us, in three states, strong, fluid and gas. The change of matter from one state to another is named as a alter in state that takes put due to the trade of warm between the matter and its environment. So, heat is the move of vitality from one framework to another, due to the contrast in temperature, which happens in three distinctive ways, which are conduction, convection and radiation as shown in figure (1) while table 1 shows the differences between conduction, convection and radiation [22-24].

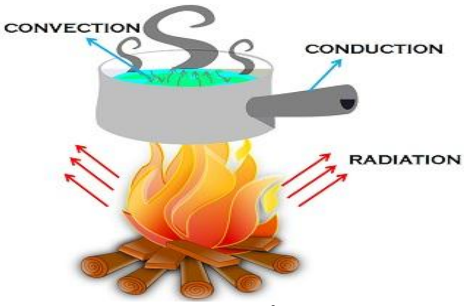

Fig. 1. Heat transfer ways.

Heat conduction, moreover called diffusion, happens inside a body or between two bodies in contact. It is the coordinate tiny trade of active vitality of particles through the boundary between two frameworks. When an object is at a different temperature from another body or its surroundings [25-27].

$$q = -K\nabla T \quad (1)$$

Where: q=is the local heat flux density (W m2), K=is the materials conductivity (W/(m K)).
∇ T=is the temperature gradient (W/K).

Heat convection depends on movement of mass from one locale of space to another. Heat convection happens when bulk stream of a liquid (gas or fluid) carries warm along side the stream of matter within the liquid.

$$q = h\Delta T \quad (2)$$

Where: q=is the local heat flux density (W m2), h=is the heat transfer coefficient (W m2 K).
ΔT=is the temperature difference (K).
Thermal Radiation. Radiation is heat exchange by electromagnetic radiation, such as daylight, with no require for matter to be display within the space between bodies.

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$$q = \varepsilon \delta T^4 \qquad (3)$$

Where: q=the power radiated from an object (W/m2), δ=is the Stefan-Boltzmann (total radiant emitted from a surface is proportional to the fourth power of its absolute temperature, this constant has the value 5.670374419 × 10−8) (Wm2K4), ε=is the emissive of the surface of a material (-).

TABLE 1. Comparison between conduction, convection and radiation [25-27]

Basis for Comparison	Conduction	Convection	Radiation
Meaning	Conduction is a process in which transfer of heat takes place between objects by direct contact	Convection refers to the form of heat transfer in which energy transition occurs within the fluid	Radiation alludes to the mechanism in which heat is transmitted without any physical contact between objects
Represent	How heat travels between objects in direct contact	How heat passes through fluids	How heat flows through empty spaces
Cause	Due to temperature difference	Due to density difference	Occurs from all objects, at temperature greater than 0 K
Occurrence	Occurs in solids, through molecular collisions	Occurs in fluids, by actual flow of matter	Occurs at a distance and does not heat the intervening substance
Transfer of heat	Uses heated solid substance	Uses intermediate substance	Uses electromagnetic waves
Speed	Slow	Slow	Fast
Law of reflection and refraction	Does not follow	Does not follow	Follow

In the current work and with the help of Gauss Seidel Method this method is very simple and is used in computers. Use the Matlab program to design and implement the proposed system (solar chimney design) to reach the highest possible efficiency of the SCPP as shown in the results. It was also found that the method can be used to solve linear system equations depending on iteration to solve the linear equation n with unknown variables. The other section deals with issues such as height, width and other dimensions. Several important tests that are detailed in the results and work on the results were discussed [28].

II. Solar Chimney Parts and Energy Balance Equation

The solar chimneys consist of a solar collector, which is an air inlet, the upper part of it is made of glass and is called (Collector or Cover) and the lower part of it is called (Absorber) and the chimney, and often there is a turbine in the lower end of it as shown in figure 2.

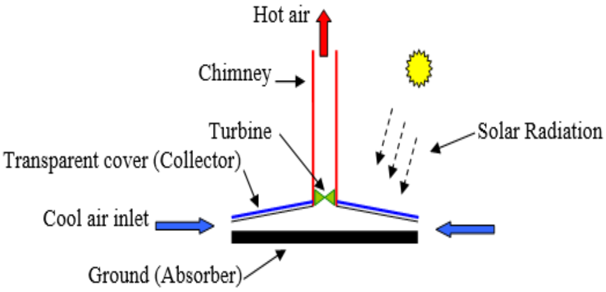

Fig 2. Schematic diagram of solar chimney power planet (SCPP).

When the chimney is heated by solar radiation, the temperature inside the chimney rises and the air density decreases, which causes the air to flow up through the chimney.

Heat can be transferred through any body as shown in figure 3.

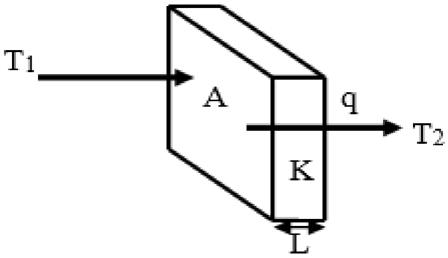

Fig. 3. Heat transfer through bodies.

Equation 4 is for thermal convection heat transfer :

$$q = KA\frac{(T_1 - T_2)}{L} \qquad (4)$$

Kinetic energy, Potential energy equations as shown in equations 5 and 6 respectively [29-32]:

$$KE=\frac{1}{2}mV^2 \qquad (5)$$

$$PE=-mgh \qquad (6)$$

Where:
m=mass, g=gravity, V=velocity and h=height

According to equations (1-6) the energy balance equations for all parts of the solar chimney can be written as shown below:

A. *Energy Balance for the Collector:*

Energy balance equation for the glass cover (Collector) is the sum of the solar radiation and the heat gained by the glass cover from the floor of the chimney (Absorber) should equal the convection heat loss to air in the flow channel and the total heat loss coefficient from glass to ambient. It can be written mathematically as:

$$[S_C A_C]+[h_{r,ab,c}A_{ab}(T_{ab}-T_f)]=h_c A_c(T_c-T_f)+[U_t A_c(T_c-T_a)] \qquad (7)$$

B. *Energy Balance for the Absorber:*

Energy balance equation for the absorber layer which depends on the solar radiation is equal to airflow convection, reflecting of the long wave radiation to the cover and conduction to air intake inside the chimney. It can be written mathematically as:

$$[S_{ab}A_{ab}]=[h_{ab}A_{ab}(T_{ab}-T_f)]+h_{r,ab,c}A_{ab}(T_{ab}-T_c)+[U_b A_{ab}(T_{ab}-T_r)] \qquad (8)$$

C. *Energy Balance for the Air flow intake:*

The energy balance equation for air flow inside the chimney can be expressed as the convection from the absorption layer must equal to the heat load (convection) from the cover plus the heat gained from the air. It can be written mathematically as:

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$$h_c A_c T_c - \left(h_c A_c + h_{ab} A_{ab} + \dot{m} C_{fl} / \gamma \right) T_f + h_{ab} A_{ab} T_{ab} = -\left(\dot{m} C_{fl} / \gamma \right) T_r \quad (9)$$

Mean temperature approximation coefficient is equal to 0.74 according to suggestion done by Ong and Chow [33-36].

Table 2. Abbreviations and Symbols

Nomenclature	Description
A_{ab}	Area of Absorber (m^2)
A_c	Area of Cover (m^2)
A_i	Cross sectional area of chimney inlet to air flow channel (m^2)
A_o	Cross sectional area of chimney outlet to air flow channel (m^2)
A_r	Ratio of A_o to A_i
h_{ab}	Conductive heat transfer coefficient for absorber ($Wm^{-2}K$)
h_c	Conductive heat transfer coefficient for cover ($Wm^{-2}K$)
$h_{r,ab,c}$	Conductive heat transfer coefficient between absorber and cover ($Wm^{-2}K$)
L_s	Stack height (m)
L_w	Length of chimney (m)
$\dot{m}$	Mass flow rate ($Kg\ s^{-1}$)
S_c	Solar radiation heat flux absorbed by cover (Wm^{-2})
S_{ab}	Solar radiation heat flux absorbed by absorber (Wm^{-2})
T_a	Ambient temperature (K)
T_{ab}	Mean temperature of absorber (K)
T_c	Mean temperature of cover (K)
T_f	Mean temperature of air in chimney (K)
T_r	surrounding temperature (K)
T	Temperature column vector=[T_g T_f T_w] T_g = mean glass cover temp, T_f=air mean temp. in the chimney, T_w = mean temp. of chimney wall
T_{curr}	Current temperature (K)
T_{prev}	Previous temperature (K)
U_b	Overall heat transfer coefficient between vertical wall and surrounding air ($Wm^{-2}K$)
U_t	Overall heat transfer coefficient from top of cover ($Wm^{-2}K$)
V	Air velocity at outlet of the chimney (ms^{-1})
σ_f	Density of air flow in chimney (Kgm^{-3})
γ	Constant for mean temperature approximation =0.74 [??]

III. SCPP SOFTWARE FLOWCHART

Matlab software with the help of Gauss Seidel Method has been done to approximate the effectiveness of the ambient and design parameters on the output and efficiency of the SCPP.

In the flowchart shown in Figure 4, the program needs to enter several variables, some of which are related to the environment and the surrounding atmosphere such as temperature and irradiance and the other section is related to the design issues of the solar chimney such as height, width and other dimensions.

Some variables is for the settings that we need to determined as inputs, for example, the number of iteration and determine the number of errors allowed that must/or need to complete the program requirements (not exceed the limit allowed) as the program contains a loop and the number of repetitions depends on the design need of the solar chimney.

The flow chart contain two subroutines, the first one for calculating the heat transfer coefficient from the inputs we enter to the program and from material property and standards constants and equations such as Boltzmann constant, Prandtl number, Grashof number, Releight number and Nusselts number as shown in figure 5.

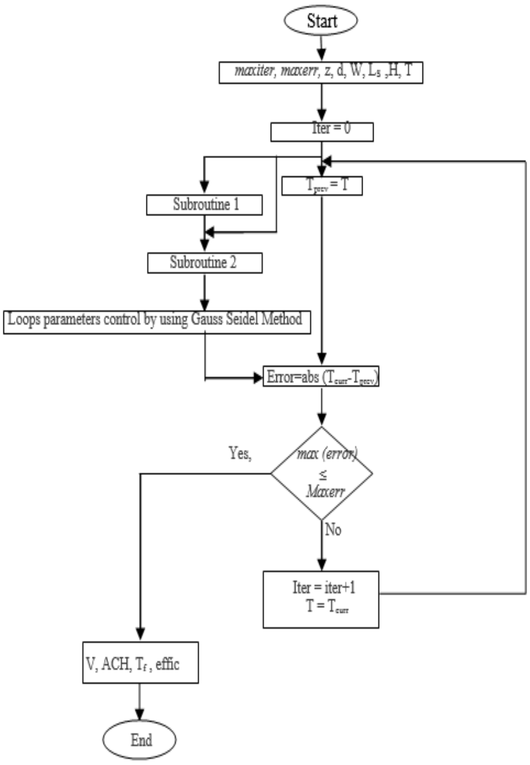

Fig. 4. SCPP flowchart

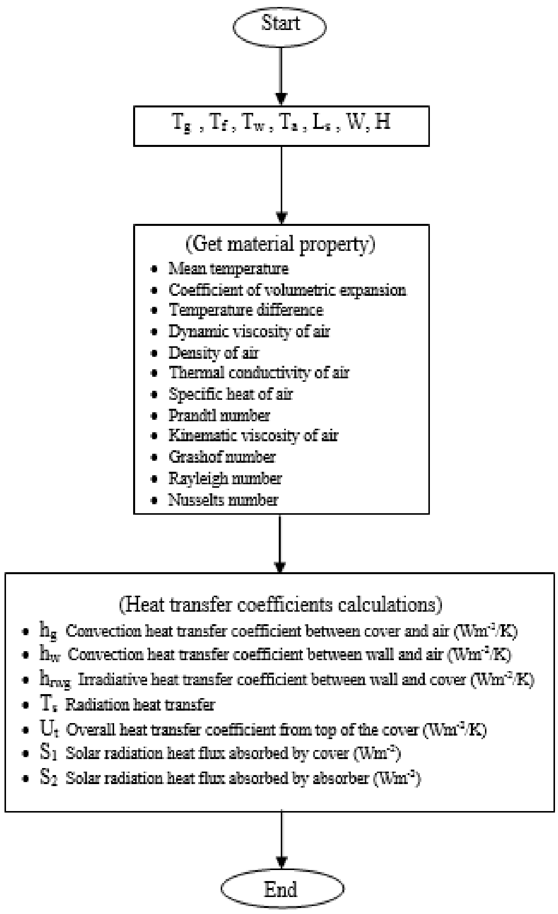

Fig. 5. Flowchart subroutine 1

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The second subroutine is for creating heat transfer coefficient matrix parameters so Gauss Seidel method which has been used in this program can approximate mathematically the effectiveness of the ambient and design parameters on the output and efficiency of the SCPP as shown in figure 6. Gauss-Seidel Method can be used to solve linear system equations depending on iteration for solving n linear equation with the unknown variables. This method is very simple and uses in digital computers for computing so we choose it

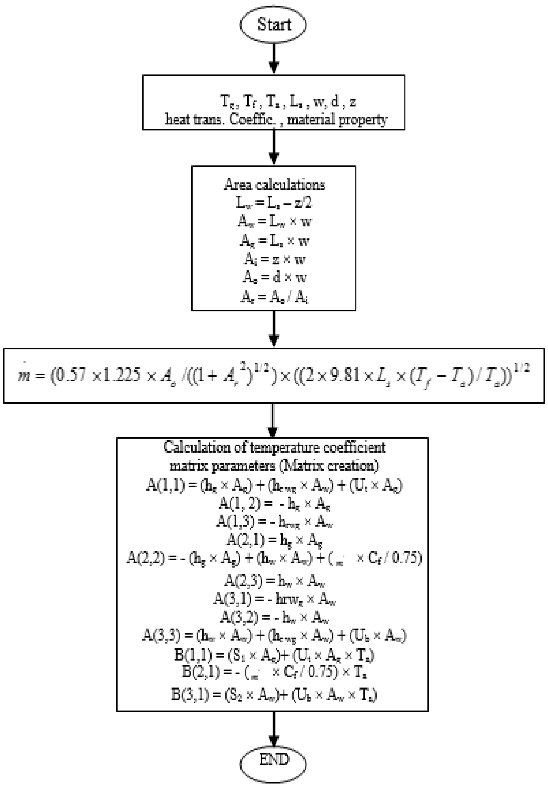

Fig. 6. Flowchart for Subroutine 2

Finally, the outputs of this program has been plotted as curves by using Matlab software as mentioned earlier, these outputs will be discussed later, the output variables are: volume flow rate (m3/s), mass flow rate (Kg/s), efficiency and number of air change per hour which all will be varied according to the set value and designing parameters that entered to the software.

IV. Results And Discussion

Many tests has been done for the city of Baghdad, parameters has been assumed in the software in order to see the effect of changing these parameters on the performance and design (Volume flow rate, mass flow rate, efficiency and ACH) of solar chimneys such as d, z, Ls and temperature according to Baghdad city season (Summer=50^0, Spring=30^0, Winter=10^0) as shown in figures (7,8,9,10,11,12).

Test 1: Ls = 20, W = 1, Summer (50^o)

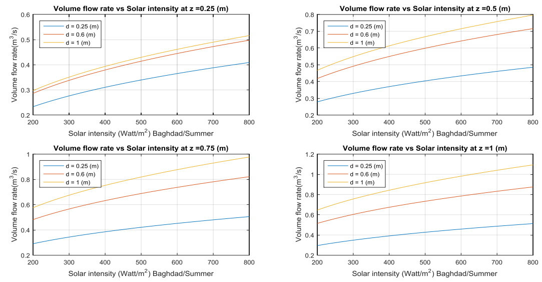

Fig. 7 a. Volume flow rate (m3/s) Vs Solar intensity (W/m2) for test 1

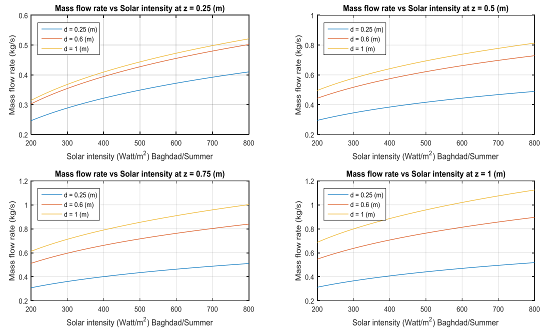

Fig. 7 b. Mass flow rate (kg/s) Vs Solar intensity (W/m2) for test 1

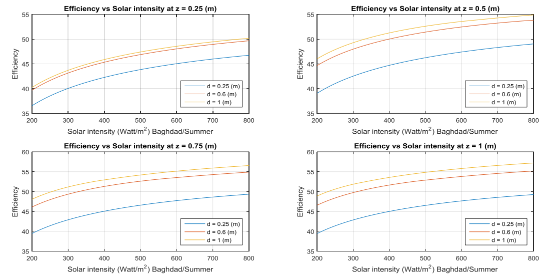

Fig. 7 c. Efficiency Vs Solar intensity (W/m2) for test 1

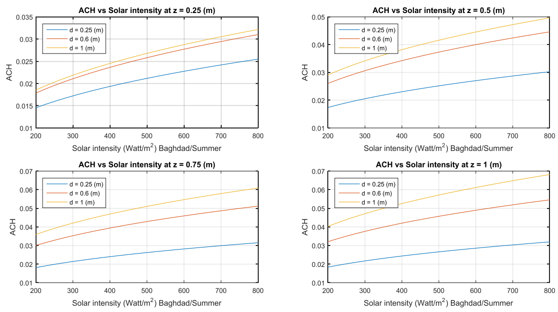

Fig. 7 d. ACH Vs Solar intensity (W/m2) for test 1

Test 2: Ls = 10, W = 1, Summer (50^o)

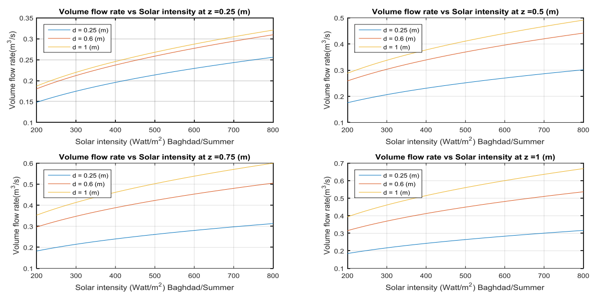

Fig. 8 a. Volume flow rate (m3/s) Vs Solar intensity (W/m2) for test 2

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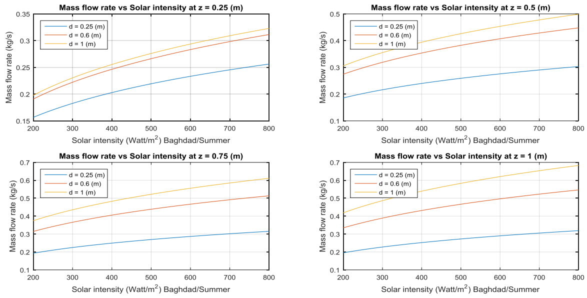

Fig. 8 b. Mass flow rate (kg/s) Vs Solar intensity (W/m2) for test 2

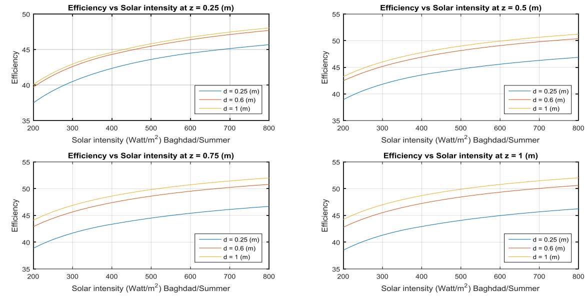

Fig. 8 c. Efficiency Vs Solar intensity (W/m2) for test 2

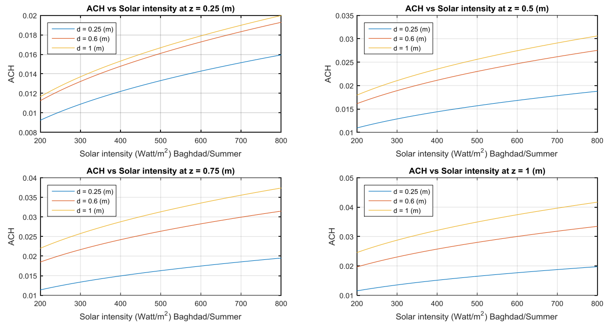

Fig. 8 d. ACH Vs Solar intensity (W/m2) for test 2

Test 3: Ls = 10, W = 1, Winter (10^{o})

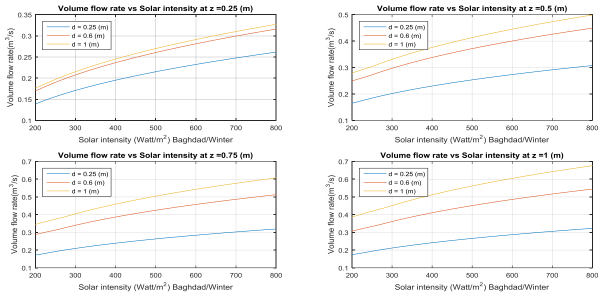

Fig. 9 a. Volume flow rate (m3/s) Vs Solar intensity (W/m2) for test 3

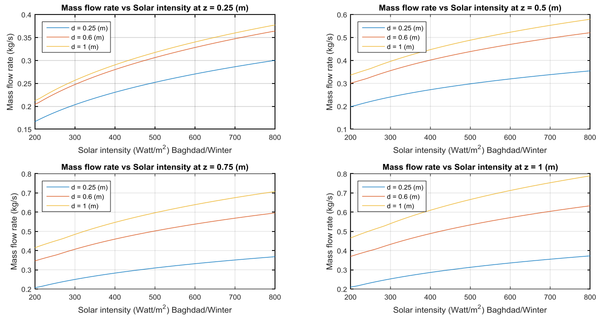

Fig. 9 b. Mass flow rate (kg/s) Vs Solar intensity (W/m2) for test 3

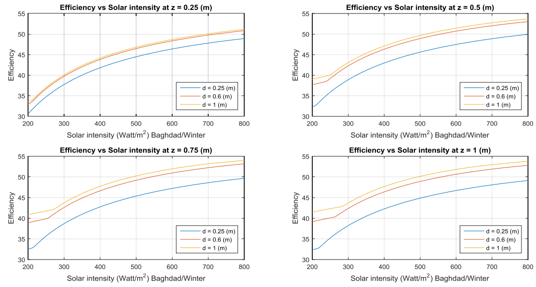

Fig. 9 c. Efficiency Vs Solar intensity (W/m2) for test 3

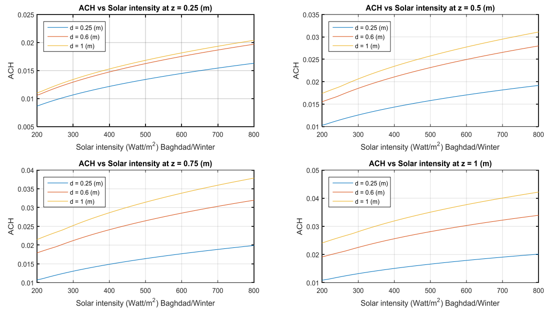

Fig. 9 d. ACH Vs Solar intensity (W/m2) for test 3

Test 4: Ls = 20, W = 1, Winter (10^{o})

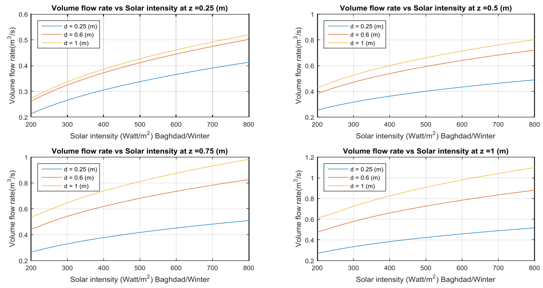

Fig. 10 a. Volume flow rate (m3/s) Vs Solar intensity (W/m2) for test 4

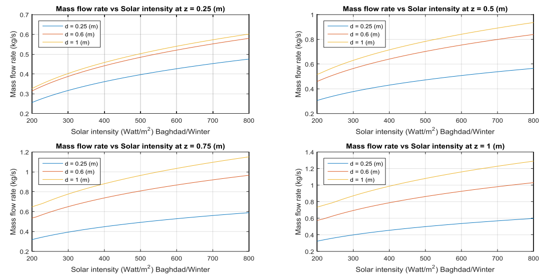

Fig. 10 b. Mass flow rate (kg/s) Vs Solar intensity (W/m2) for test 4

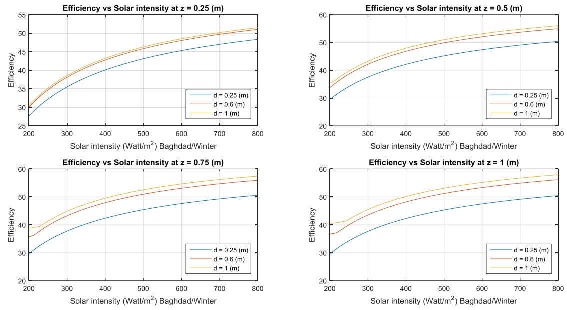

Fig. 10 c. Efficiency Vs Solar intensity (W/m2) for test 4

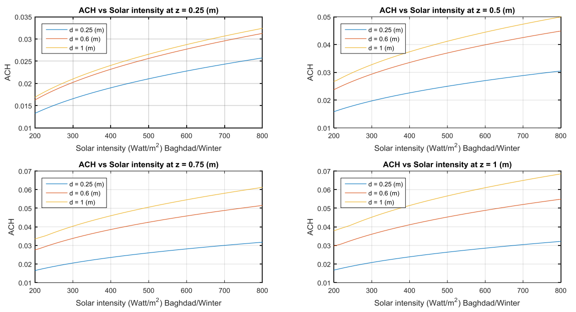

Fig. 10 d. ACH Vs Solar intensity (W/m2) for test 4

Test 5: Ls = 20, w = 1, Spring (30^o)

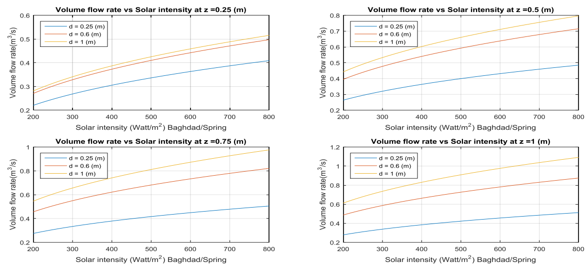

Fig. 11 a. Volume flow rate (m3/s) Vs Solar intensity (W/m2) for test 5

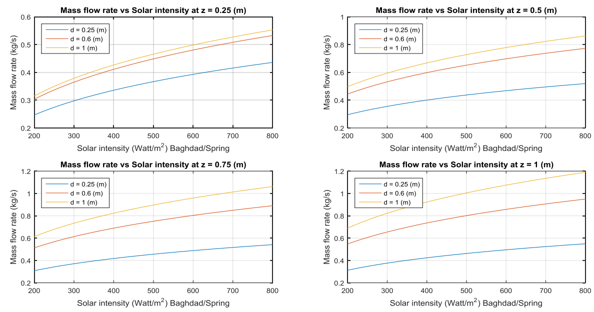

Fig. 11 b. Mass flow rate (kg/s) Vs Solar intensity (W/m2) for test 5

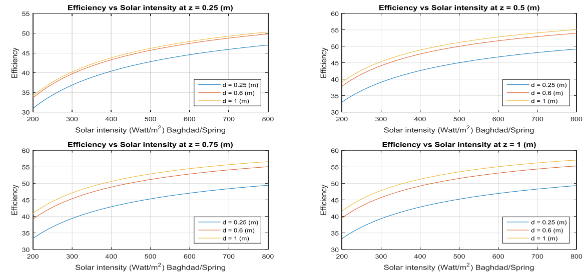

Fig. 11 c. Efficiency Vs Solar intensity (W/m2) for test 5

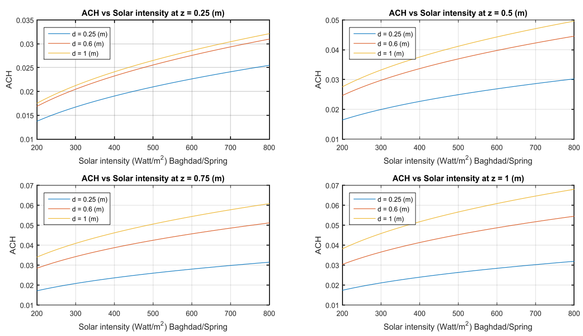

Fig. 11 d. ACH Vs Solar intensity (W/m2) for test 5

Test 6: Ls = 10, w = 1, Spring (30^o)

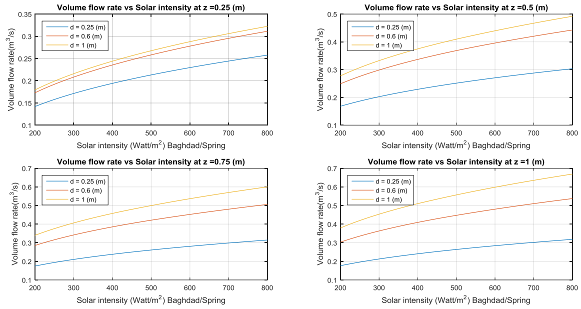

Fig. 12 a. Volume flow rate (m3/s) Vs Solar intensity (W/m2) for test 6

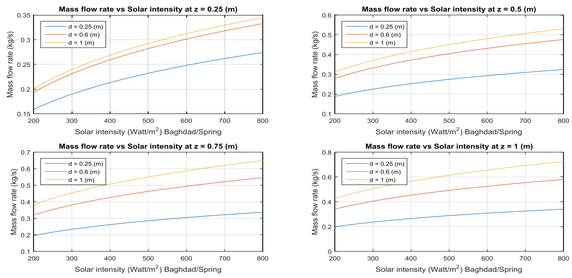

Fig. 12 b. Mass flow rate (kg/s) Vs Solar intensity (W/m2) for test 6

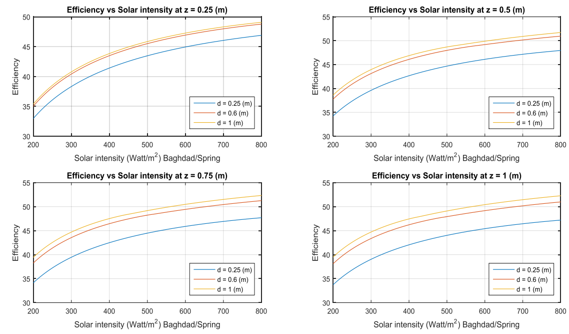

Fig. 12 c. Efficiency Vs Solar intensity (W/m2) for test 6

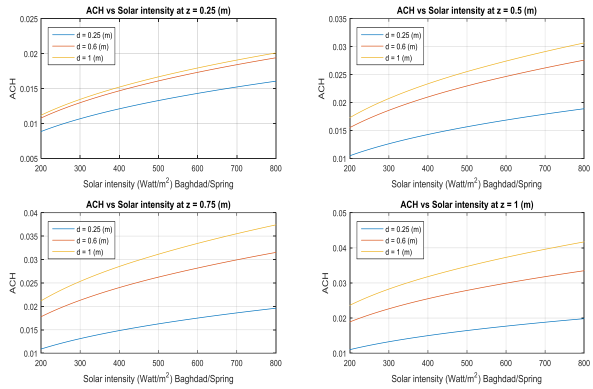

Fig. 12 d. ACH Vs Solar intensity (W/m2) for test 6

Discussion of the results is explained as follow:

Volume flow rate ($\dot{V}$): as shown from the results the volume flow rate is increase when z and d increase, the volume flow rate is not affected by temperature change due to seasons also the volume flow rate increase about 60% when Ls is double. Volume flow rate increase proportionally with irradiance (H).

Mass flow rate ($\dot{m}$): as shown from the results the mass flow rate is proportional with increasing z and d, the mass flow rate is affected by temperature change due to seasons at high Irradiance while its not affected at low H, also the mass flow rate increase about 62% when Ls is increase from 10 to 20. Mass flow rate increase proportionally with irradiance (H).

Efficiency (ζ): from the results the efficiency increase when z and d increase, the proportional of increasing of efficiency is greater at high z, the efficiency increase when temperature increase specially at low H, the efficiency increase about 7% when Ls is double. Efficiency increase proportionally with irradiance (H).

Number of air change per hour (ACH): ACH increase when z and d increase and not affected by change temperature during seasons change, the increment of ACH according to increasing H is constant when temperature change, when Ls increase twice the ACH increase about 60%, ACH increase when H increase.

V. Conclusion

After performing the simulation using Matlab with the aim of obtaining a performance evaluation within the default specifications. Researchers suggest this paper in a direct way to address a specific city, which is Baghdad. The researchers adopted a simple and focused study in order to evaluate the mechanism of energy production from the turbine systems for solar chimneys. The researchers worked on reaching a basis for how to improve the turbine systems for solar chimneys and the steps to design and develop their work through the use of a simple and accurate mathematical model that represents chimney power stations. It can be said that researchers will work to use systems with optimum operation in the next study, by presenting a mathematical model that meets the requirements of the entire system.

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