DOI: http://dx.doi.org/10.4314/gjpas.v21i2.8

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 21, 2015: 155-169

 ISSN 1118-0579
www.globaljournalseries.com, Email: info@globaljournalseries.com

EXPERIMENTAL STUDY IN NATURAL CONVECTION

M. OUSMANE, B. DIANDA, S. KAM, A. KONFÉ, T. KY AND D. J. BATHIÉBO

(Received 26 August 2015; Revision Accepted 26 October 2015)

ABSTRACT

The study of thermal and ventilation parameters, obtained in a transient, laminar solar chimney of reduced dimensions, (1 < m <3) m with a square collector (side = 2m) is presented. Experimental measurements has been made to determine the temperature of the absorber and the fluid in the collector, it is shown that at the entrance of the chimney, the temperature of the absorber decreases slightly while that of the fluid is maintained at a maximum level. Temperature differences were observed up to 32°C between the atmosphere and the fluid in April. A temperature variation at the absorber depending on the stack height is presented. Temperature measurements in the chimney, at various heights depending on the axial coordinate, show a variable temperature profile. It is, from these, shown that, in the selected interval of stack height, the average speeds of output increase linearly as a function of stack height. For a chimney of 3m in height and 20cm in diameter, a maximum speed of approximately 0.7 ms^{-1} was observed. The lack of appropriate equipment handicaps the velocity measurement at the chimney entrance. Thus, the results of simulations with the computer code COMSOL 5.1 has confirmed temperature values measured at the chimney entrance and after this, velocity values are determined.

KEYWORDS: 1- Solar chimney, 2- Laminar convection, 3- Temperature, 4- Outlet velocity

INTRODUCTION

Solar chimneys are traditionally used for drying agro-food products, the renewal of air in silos, barns, greenhouses and houses and more recently for generating electricity. Less than 20% of the population in the Sahelian countries have access to electricity, Ministère de l'Environnement et du Développement Durable, (2011). However, energy is one of the challenges of urban growth in West Africa. This often concerns arrears agricultural countries with low industrial base and a population using wood and charcoal as major fuels. Nevertheless, their economies often heavily depend on imports of oil and gas. However, they have one of the largest solar deposits in the world, with an average intensity of sunshine ranging between 5.5 $kWh.m^{2}day^{-1}$ and 6.5 $kWh.m^{-2}day^{-1}$ and duration from 3 000 to 3 500 hours per year. But it remains very low value in use, especially as regards thermal systems. However, these socio-economic and climatic conditions are favorable for the development of solar chimneys for the production of electrical energy or the drying of agro-food products.

1.1 Experimental models

The first prototype tower was built in Manzanares in 1981, thanks to the team of Professor Schlaich, Haaf *et al*., (1983); Haaf *et al*., (1984), in Spain. It worked from 1982 to 1989. In general, the collecting surface (collector) is made of a transparent cover (made of glass or plastic or a combination of both) held at a certain height from the ground, creates a greenhouse that is open to the outskirts but attached to a chimney in the centre. The thermal draught or "chimney effect" induces a depression and draws air from the outside through the sensing surface. The speed of air movement is determined by the temperature gradient within the stack. The kinetic energy gained by the fluid is converted into mechanical energy and then into electrical energy by turbines according to Figure 1. The output power profile, in this type of solar chimney without storage, is in perfect accordance with that of daily radiation. Note that this tower was used as an information provider Haaf *et al*., (1983); Haaf *et al*., (1984); Schlaich *et al*., (1995).

M. Ousmane, Laboratory of Renewable Thermal Energies, UFR / SEA, 03 BP 7021, University of Ouagadougou, Burkina Faso
B. Dianda, Laboratory of Renewable Thermal Energies, UFR / SEA, 03 BP 7021, University of Ouagadougou, Burkina Faso
S. Kam, Laboratory of Renewable Thermal Energies, UFR / SEA, 03 BP 7021, University of Ouagadougou, Burkina Faso
A. Konfé, Laboratory of Renewable Thermal Energies, UFR / SEA, 03 BP 7021, University of Ouagadougou, Burkina Faso
T. Ky, Laboratory of Renewable Thermal Energies, UFR / SEA, 03 BP 7021, University of Ouagadougou, Burkina Faso
D. J. Bathiébo, Laboratory of Renewable Thermal Energies, UFR / SEA, 03 BP 7021, University of Ouagadougou, Burkina Faso

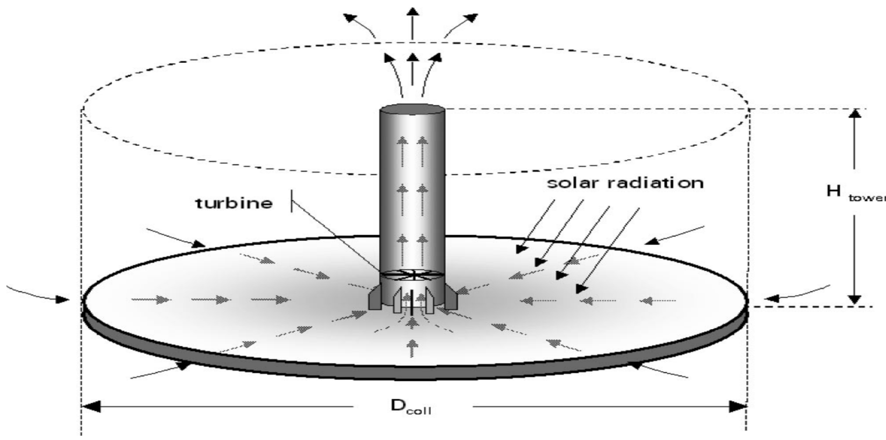

Figure 1: Solar chimney principle. Schlaich, (2005)

Table 1: Main features of the Manzanares power plant Sclaich *et al*., (2005)

Tower height	194.6 m
Tower diameter	10.16 m
Average diameter of the greenhouse	244 m
Average height of the greenhouse	2m
Increase in air temperature in the collector	20°C
Air velocity in the chimney	15 m / s
Rated power	50 kW
Area of collector covered with plastic membrane	40 000 m^2
Area of collector covered with crystal	6000 m^2

Subsequently, referring to Table 1, many prototypes with quite varied dimensions were tested. Table 2 summarizes the thermo-hydrodynamic performances obtained by Pasumarthi and Sherif, (1998b); Golder (2003); and Akbarzadeh *et al*., (2009); Zhou *et al*., (2007); Ferreira *et al*., (2006); and Maia *et al*., (2009); Motsamai *et al*., (2013); Hartung *et al*., (2008); Ahmed and Chaichan ., (2011); Kasaeian *et al*., (2011); Bugutekin., (2012); Mehla *et al*., (2011); Kalash *et al*., (2013); Kasaeian *et al*., (2014).

Table 2: Summary of performances with some experimental models. Xinping and Yangyang, (2014).

Country	Chimney height (m)	Chimney diameter (m)	Collector area (m^2)	Collector composition	Maximum velocity (m/s)	∆T collector and ambient air (K)	Year of construction
Florida (USA)	7,92	2.44-0.61	263	Plastic	3.1	28,1	1997
Bundoora (Australia)	8	0.35	13.8	-	1	11	2002
Wuhan (China)	8.8	0.3	78.5	Glass	2.81	24.1	2002
Bello Horizonte (Brésil)	12.3	1	491	Plastic	2.9	27 ±2	2003
Gaborone Bostwana	22	2	225	Glass	7.5	6.8	2008
Weimar (Germany)	12		420	Plastic	2.42	17.2	2008
Baghdâd (Iraq)	4	0.2	28.3	Plastic	2.309	22	2009

Zanjan (Iran)	12	0.25	78.5	Plastic	2.9	26	2010
Adıyaman (Turkey)	17.15	0.8	572.6	Glass	5.5	26	2010
Hamirpur (India)	0.8	0.08 0.10 0,12	1.5	Plastic	0.49 0.45 0.36	1.7 2.5	2011 2011
Damascus (Syria)	9	0.31	12.5	Glass	2.9	19	2012
Tehran Iran	2	0.2	7.0	Glass	1.3	11.05	2013

Amir and Hadi, (2015) brought an innovation to the design of a solar tower of 2.6m in height, with a cylindrical collector of 0.92m in height and 0.9m in diameter. They combine hubs that can track the sun's path, reflecting the radiative flux received on the glass walls of the collector. Top speed achieved then reaches 5.12 $m.s^{-1}$. This is very important as regards the dimensions of the prototype.

1.2. Theoretical models

Many theoretical models of solar chimney have been developed, but few comprehensive experiments were conducted on prototypes outside that of Professor Schlaich, Haaf *et al*., (1983) to confirm their validity. Note that five simple theoretical models given in literature were identified and compared with CFD results. Firstly, the model of Chitsomboon *et al*., (2001) is the only one which is in perfect agreement with CFD results but underestimates plant's performances. Secondly, the model of Schlaich *et al*., (2005) fits well with CFD results. Thirdly, the model of Ming et al., (2006) diverges from CFD results and overestimates plant's performances. Fourthly, the model of Zhou et al., (2009) also diverges from CFD results and overestimates plant's performances. Fifthly, the model of Koonsrisuk and Chitsomboon., (2009) gives reasonable solutions comparable to Schlaich *et al*., (2005).

Nevertheless, it was Mullett (1987) who began the development of theoretical models of solar chimney while expressing that the overall efficiency is proportional to the chimney height. Referring to data from Manzanares prototype Padki and Sherif, (1989) elaborated models liable to produce significant energy in the medium and long term. Yan *et al*., (1991) referring to a comprehensive analytical model used correlations allowing them to obtain the equations for air speed, air flow rate, output power and thermo fluid efficiency. Padki and Sherif, (1992) presented a brief presentation on the geometric effects and certain operating parameters on the performance of a solar chimney. In the late 90s, Pasumarthi and Sherif, (1998a) built a reduced prototype to study the effects of various geometric parameters related to air temperature, air velocity and output power of the solar tower. Besides, Pasumarthi and Sherif, (1998b) studied the performance of a collector by increasing the base of the collector and introducing a storage system. These two innovations allowed them to increase the total output power of the whole system. In addition, a brief analysis of the economic costs of the system is presented. Bernades *et al*., (1999) were the first to use the CFD code (Computational Fluid Dynamic) in solar chimney convective flow study. They presented a solution for the Navier-Stokes equations and energy for a steady laminar natural convection in providing for its thermo-hydrodynamic behavior, from the finite volume method in generalized coordinates. This method supplied a detailed view of geometric effects, and operational optimal characteristics. Kröger and Blaine, (1999) assessed the influence of ambient conditions and pointed that the air humidity could influence the driving force with the possibility of air condensation. During the same period Buys and Kröger, (1999) developed analytical relationships to determine the pressure difference due to friction phenomena and heat transfer in order to develop a radial flow between the roof and the collector. Gannon and Von Backström, (2000) used a solar collector model by coupling the temperature and mass flow to study the friction phenomena inside the chimney, the turbine and kinetic energy loss at the chimney outlet. Simulation results of this experimental work compared with those of a small central allowed to predict the performance of a large-scale plant.

During the same year they developed a one-dimensional model of a compressible flow for the calculation of thermodynamic variables depending on the chimney height, rubbing against the wall chimney, additional losses, and the location variation. Chitsomboon (2001) also developed a mathematical model; the results were in agreement with those of Schlaich *et al*., (2005). Bernardes and Von Backström, (2010) undertook the study of the performance of two models of chimney. Larbi *et al*., (2010) presented an analysis of the energy performance of a solar chimney in the strongly sunny region of Adrar (south of Algeria); it may provide up to 140-200 kW of electricity throughout the year. Moreover, Chergui *et al*., (2010) have developed a CFD model compatible with the Benchmark of Vahl Davis, (1983) for natural convection. Sangi *et al*., (2011) demonstrate that pressure decreases along the collector and that its minimum value is located at the bottom of the chimney while the latter was considered positive and increasing throughout the flow in the collector by Pastohr *et al*., (2004). Tayebi and Djezzar,

(2012) present a numerical model of the laminar natural convection in vorticity-stream function in hyperbolic coordinates formulation. They prove that the airflow varies not only with the roof-floor distance of the collector, but also with the Rayleigh number; allowing the manufacturer to optimize the location of its turbine. In Egypt, El Haroun, *et al*., (2012) devised a mathematical model that could determine the power output and predict the effects of changes in environmental conditions. Tayebi and Djezzar, (2013) also established a digital model of a solar chimney with curved junction. They showed that maximum speed is achieved at the chimney entrance. koonsrisuk and Chitsomboon, (2013), Ming *et al*., (2013), Putkaradze *et al*., (2013), showed that the geometry of solar chimneys influence their performance. Ghalamchi, *et al*., (2013), Kasaeian, *et al*., (2014) proceeded to a theoretical performance evaluation of a solar chimney using the FLUENT CFD code and validated their study by using an experimental prototype. The parameters considered concerned the inclination of the collector, the diameter of the chimney and the height of the collector inlet. Peng-hua Guo *et al*., (2014) show that for a fixed stack diameter, there is a maximum value of the collector radius beyond which the output power remains substantially constant.

In conclusion these studies confirm the feasibility of the system. It is then necessary to conduct experiments based on local meteorological data, to optimize geometry settings in order to improve the overall efficiency, and finally, to locally produce technically well controlled systems that are affordable by rural populations.

2. Description of our prototype

An experimental prototype of solar chimney shown in Figure 2 has been designed at the Thermal Renewable Energy Laboratory of the University of Ouagadougou, Burkina Faso. It consists of a square collector 2m side topped with a chimney whose height can vary between 1m and 3m. The choice of a square collector is linked to the need for simplicity in the construction of such a prototype in rural areas. The chimney with 20cm of diameter is made of mild steel 1.5 mm thick and insulated with TRAPALU-40 which is a weather resistant insulator. The collector of the tower consists of a glass roof covering an absorber. The roof of the collector is composed of four (4) panes of soda-lime glass (SiO_2 72% silica, 14% sodium hydroxide, 10% lime, and 5% alumina magnesia oxide), a square meter of surface and 5 mm thick, forming an angle of 4 ° between the collector inlet and that of the chimney. The works of Ghalamchi, *et al*., (2015) show that in the case of small power systems using solar chimneys, a near zero slope is the most appropriate. The absorber is a zinc-aluminum sheet, thickness 0.35mm, painted matte black and isolated by 20cm polystyrene at its lower surface. Numerous other materials have been used as absorbers but do not reach the temperature level obtained with this material which has an average thermal conductivity of 140W / m.K, a density of 2.8 $kg.m^{-3}$.

Figure 2: View of the solar chimney equipped with its temperature sensors

3. Experimental Protocol

Our study was first to measure temperatures from the collector inlet to the center of the chimney and then at different heights in the chimney according to Figure 3. These measurements are made with type K thermocouples connected to two temperature recorders (MIDI LOGGER GL 200) shown in figure 2. The evaluation of speed at the inlet and outlet of the chimney is effected by means of an anemometer connected to a datalogger D02003, precision AP472S2 0.05 m. s^{-1} for a speed between 0.1 and 0.99 m.s^{-1} ; and 0.15 ms^{-1} for a speed between 1 and 5 ms-1; and finally we measure global solar radiation with a solarimeter KIMO SL 100 of 5% accuracy.

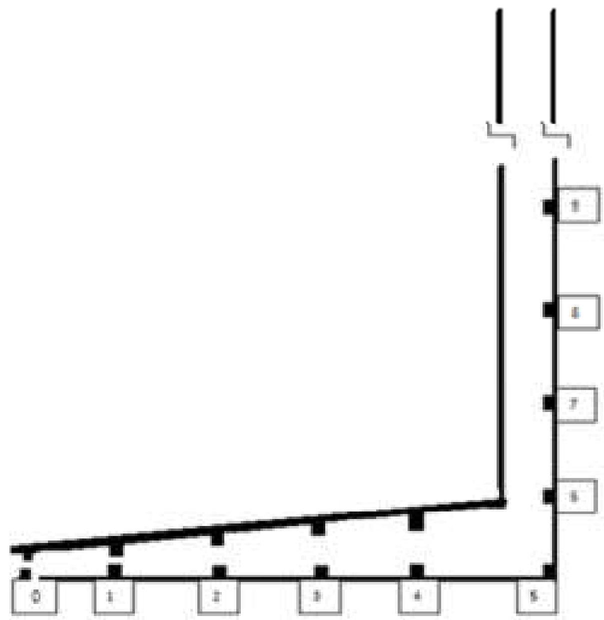

Figure 3: Sensors emplacements for thermal measures in the fluid and on absorber

4. RESULTS AND DISCUSSION

4.1. Temperature evolution of the absorber and fluid in the collector

4.1.1. Temperature evolution according to radiation

In general, curves showed temperature levels all the more so higher as the global radiation was more important according to Figure 4. It should be noted that thermocouple 5 was located at the outlet of the collector, on the absorber, at the intersection point determined by the central axis of the tube and the absorber plane shown in Figure 3.

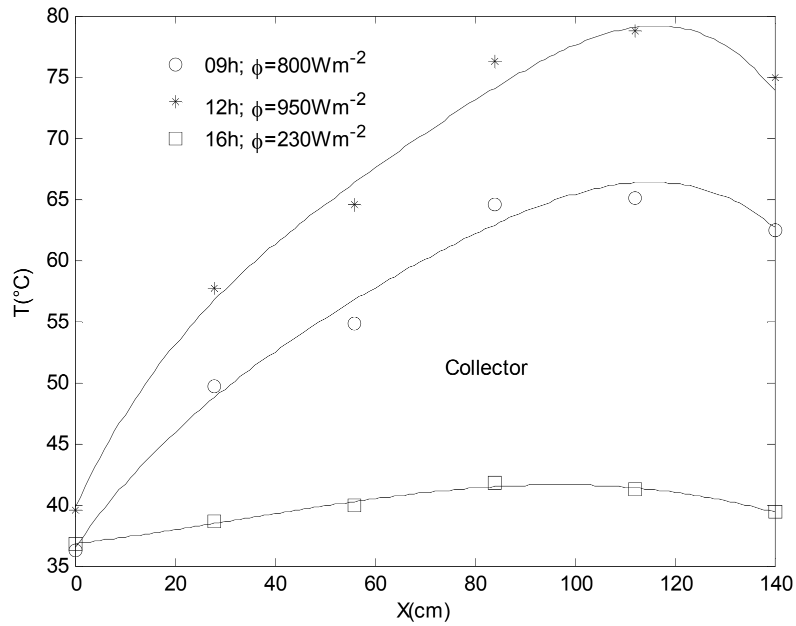

Figure 4: Temperature variations along the absorber (H = 3m)

Several authors Sangi *et al.*, (2011); Ghalamchi *et al.*, (2013); Kasaeian *et al.*, (2014); Zhou *et al.*, (2007) show no changes up to this point which temperature is slightly lower but illustrates an important physical phenomenon according to Figure 3. The heat transfer between the fluid and the absorber reaches its maximum between the positions of sensors 4 and 5. This result was also observed by Ghalamchi *et al.*, (2015). Indeed, initially, the volume of incoming cold air heats up under the effect of intense solar radiation and as long as the fluid moves towards the center, the ratio of volume of the fluid in exchange surface increases, causing a slight drop in the temperature of the absorber.

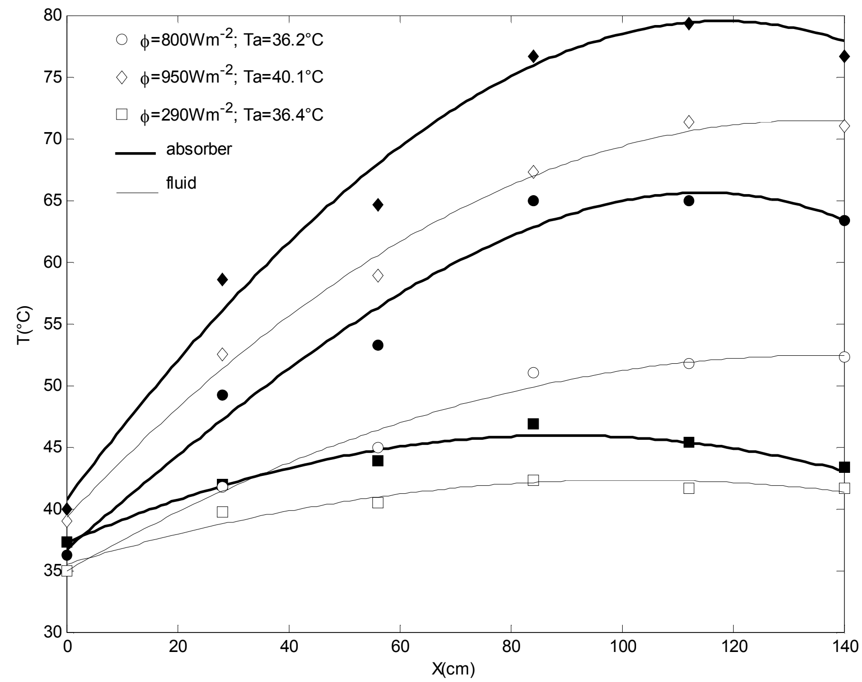

Figure 5: Evolutions of fluid temperatures compared to the temperatures of the absorber (H = 3m)
On the contrary, fluid temperature stabilizes at a maximum level referring to figure 4.

4.1.2. Absorber temperature evolution as a function of chimney height

An increase in chimney height results in an intensification of convective motions within the prototype. The heat transfer coefficient by convection between the fluid and the absorber increases. Then we note temperatures decreasing along the absorber according to Figure 6.

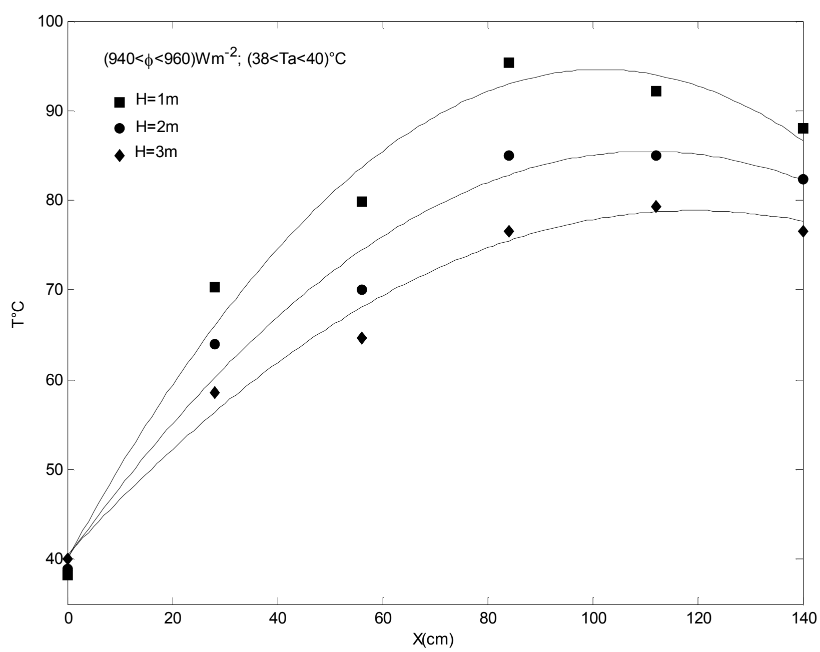

Figure 6: Absorber temperature evolution as a function of chimney height

4.2. Axial evolution of temperature in the chimney

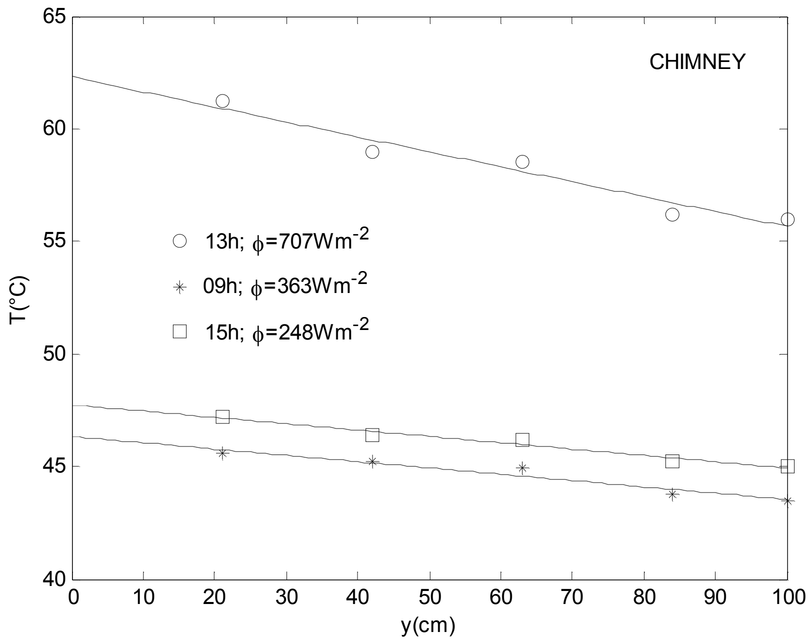

Figure 7: Variation of temperature in the chimney (H = 1m)

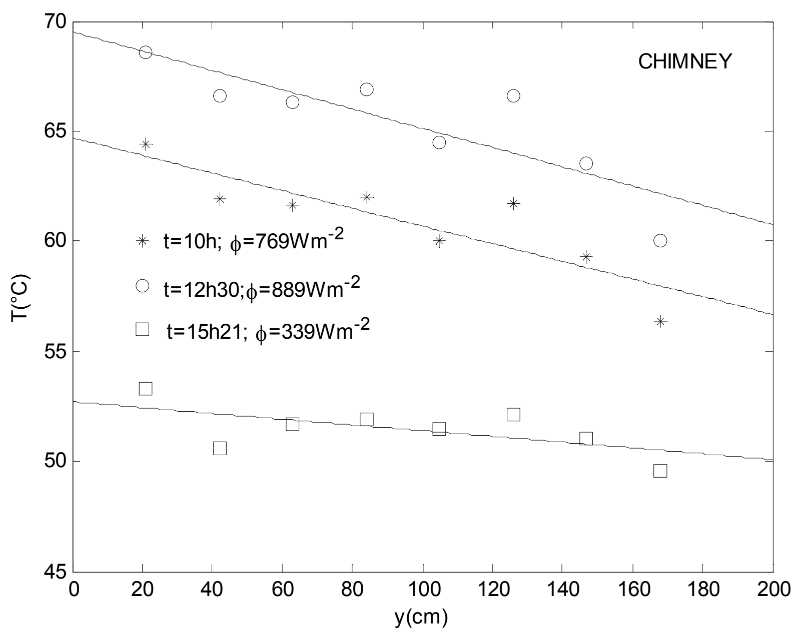

Figure 8: Variation of temperature in the chimney (H = 2m)

In the chimney, the temperature profile is quite linear for heights from 1 to 2 m according to Figure 7 and Figure 8. Indeed, temperature gradients between the inlet and the outlet of the chimney are then relatively large. The result is a nearly linear profile and slightly decreasing according to a quadratic curve.

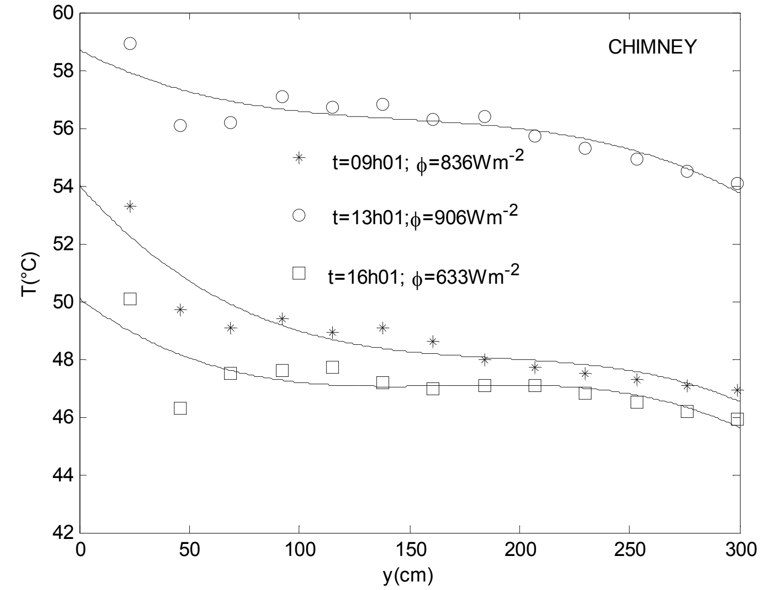

Figure 9: Variation of temperature in the chimney (H = 3 m)

On the contrary, when the height increases, the convection intensifies, temperature gradients are lower between two neighboring points, leading to an almost hyperbolic profile halfway up as shown in Figure 9.

4.3 Study of flow speed

4.3.1 Study of the release speed as a function of stack height

The preheated air at the collector enters the chimney, the significant heat energy gained turns into kinetic energy causing a convective upward flow in the chimney. For April 14, 2015, the overall radiation between 10 o'clock and 16 o'clock is shown in Figure 10. Then we measure the output speed of the chimney over time, for heights ranging from 1 to 3m. Average speeds are calculated from hourly rates. It is then observed that the output speeds grow according to chimney height as indicated in Figure 11.

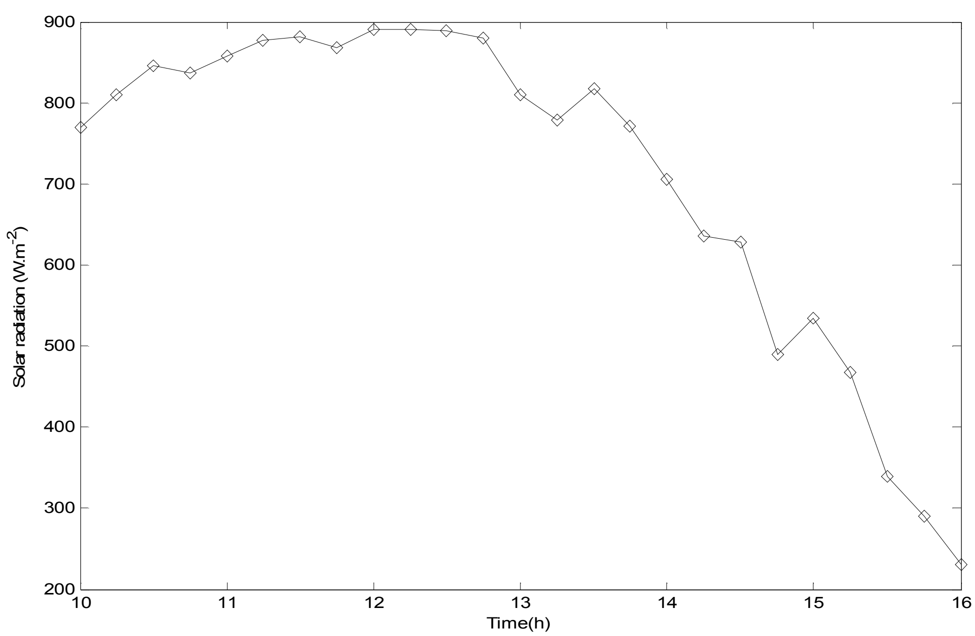

Figure 10: Global Solar Radiation (April, 14th 2015)

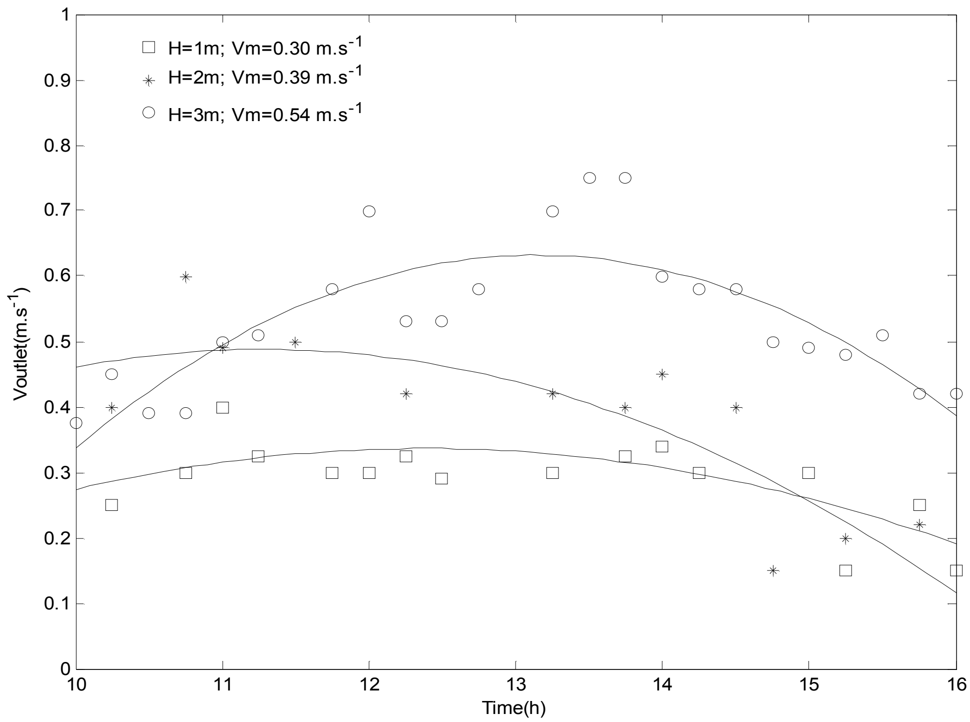

Figure 11: Evolution of output speeds as a function of time for different chimney heights during the day of April 14, 2015.

An increase in chimney height results in an increase in output speed. The formula of Unger (1988) illustrates the phenomena observed in Figures 10, 11 and 12; thus:

$$V_{tower,max} = \sqrt{2.g.H_{tower}.\frac{\Delta T}{T_0}}$$

With ΔT representing the variation of temperature between the outlet of the chimney and the atmosphere, T_0 is the ambient temperature, H_{tower} , the chimney height. Nevertheless notice an important fluctuation in output speeds linked to variations of radiation over time (clouds, dust, wind, etc...)

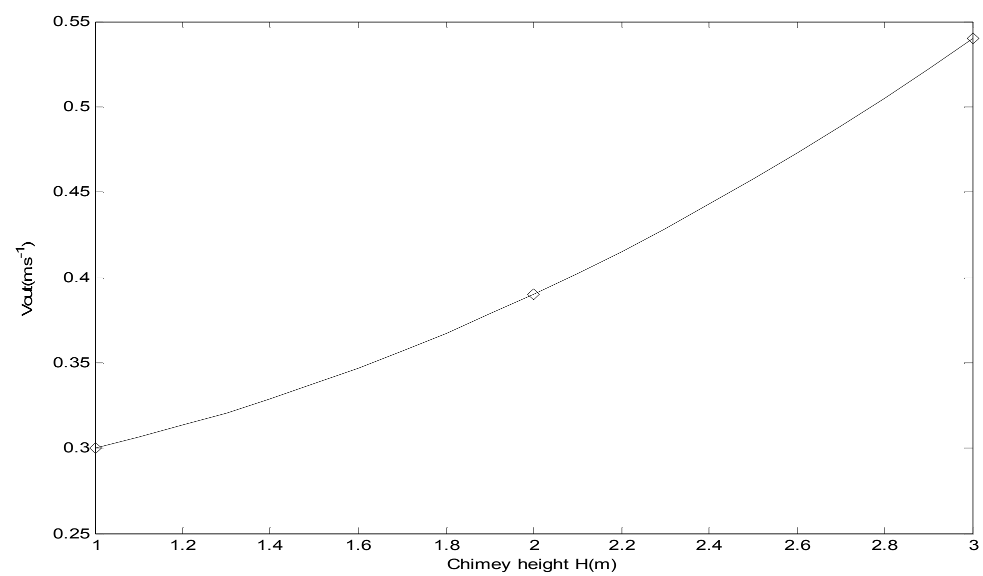

Figure 12: Variations in average speed as a function of chimney height.

The representation of the average speed during a very sunny day for different heights, confirms the previous observations.

4.3.2. Determination of speed in the collector and the chimney, using the digital code COMSOL 5.1

With no great precision measuring apparatus adapted to the geometry of the tower (e.g., flexibility and telescopic rod for measurements in the duct), it is proposed to complete this study by simulating the operating conditions of our solar chimney with natural convection. The thermo-physical conditions and the boundary conditions used are summarized in table 3. The speed distribution in Figure 14, corresponding to the temperature distribution of figure 13 is presented.

Table 3: Thermo-physical and boundary conditions

Ambient temperature (°C)	**Mean Global radiation ($W.m^{-2}$)**	**h (convection coefficient between glasses and outside air) $W.m^{-2}.K^{-1}$**	**Insulator Thermal conductivity $W.m^{-1}.K^{-1}$**
30	920	2.5	0.025

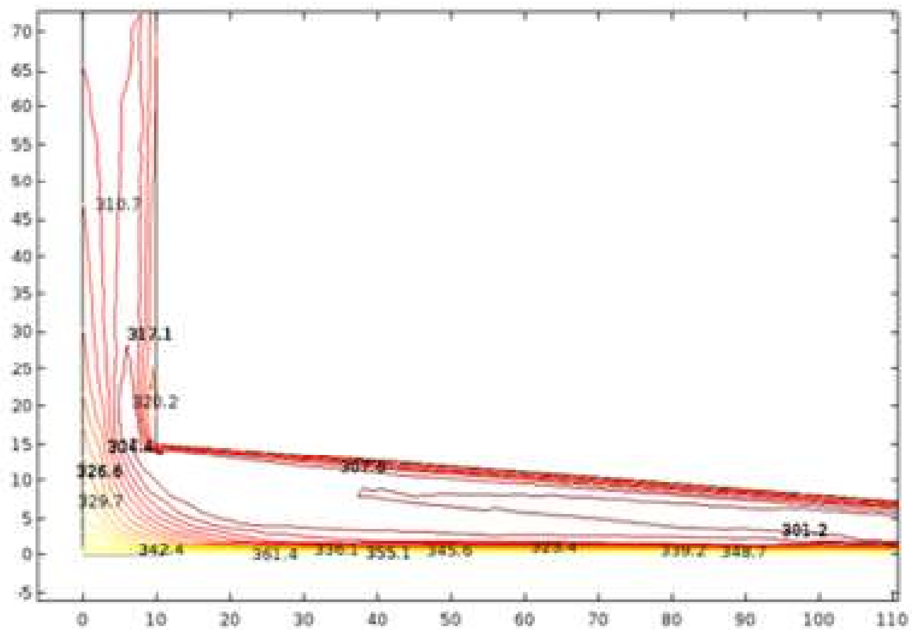

Figure 13: Temperature distribution in the chimney

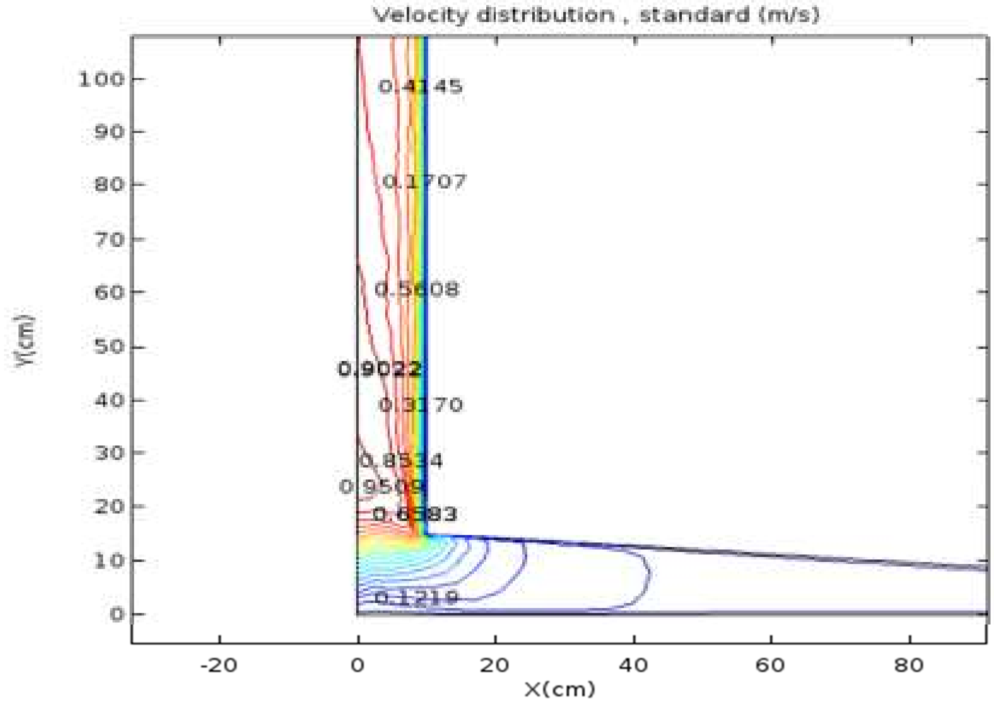

Figure 14: Velocity distribution in the chimney

4.4. Application to the production of electricity and solar drying

Assuming average value for the coefficient of performance (0.50), one can roughly estimate the expected electric power with a small turbine placed at the entrance of the chimney, in small laboratory prototype built referring to Table 4. With: α = 0.5; ρ = 1.2; S = 0.0314m²

Table 4: Power obtained as a function of stack height

Collector area (m²)	Chimneyheight (m)	Maximum fluid temperature (°C)	Maximum absorber temperature (°C)	Maximum velocity (m.s^{-1})	Power (10^{-4} W) $P = \frac{1}{2}\alpha.\rho.S.V^3$
4	1	72	95	0.30	2.54
4	2	53	84	0.39	5.60
4	3	42	75	0.54	15.00

Drying of fruits and vegetables is usually done around 60°C if we want to preserve the nutritional quality of products. Some trays can be placed at the bottom of the chimney where the fluid temperature can reach 72 ° C. This level of air temperature with speeds consistently above 0.1m.s^{-1} is satisfactory. Indeed, in general, failing to have the considered product drying speed curves, it is always recommended to keep a temperature of the air at its arrival on the product of 10°C above the maximum temperature permissible by the product. In fact, the more water the product contains, the more water evaporation enables the cooling of the product. Thus, at the beginning of drying, the temperature must be as high as possible to ensure rapid drying. This will require the air to have a temperature of at least 70°C at the beginning of drying. At the end of the drying, it is necessary to ensure that the product temperature does not exceed 65°C, i.e. when the humidity of the product has decreased considerably.

CONCLUSION

From the study, the following conclusions could be drawn:

1. At the entry of the chimney the temperature of the absorber decreases slightly while that of the fluid is maintained at a maximum level.
2. An increase in stack height results in increased convective motions in the prototype, with an increase in fluid temperature at the loss of that of the absorber.
3. The highest speeds are achieved at the entrance of the chimney but quickly decrease in order down the axis. Flow can be enhanced in this area with the aid of curved junctions. This confirms the

choice in this area by several authors for the turbine installation.

4. The ideal place for drying racks corresponds to the area above the entrance of the chimney which is the relatively high temperature seat with maximum flow rates. These conditions are favorable to mass and heat transfer.

This study confirms the feasibility of the system, and also highlights the need to optimize ventilation parameters for thermal power production and foodstuffs conservation.

REFERENCES

Ahmed, S. T and Chaichan, M. T., 2011. A study of free convection in a solar chimney model. Eng. Technol. J, 29, 2986–2997.

Akbarzadeh, A., Johnson, P and Singh, R., 2009. Examining potential benefits of combinaient a chimney with a salinity gradient solar pond for production of power in salt affected areas. Sol. Energy, 83, 1345–1359.

Amir, R. S., Hadi, I., 2015. Experimental and numerical investigation on an innovative solar chimney. Energy Conversion and Management, 95, 446–452.

Alibakhsh, K., Mehran, G and Mehrdad, G., 2014. Simulation and optimization of geometric parameters of a solar chimney in Tehran. Energy Conversion and Management, 83, 28–34.

Bernades, M. A. D. S., Valle, R. M and Cortez, M. F. B., 1999. Numerical analysis of natural laminar convection in radial solar heater. Int. J. Therm. Sci, 38, 42-50.

Bernades, M. A. D. S and Von Backström, T. W., 2010. Evaluation of operational control strategies applicable to solar chimney power plants. Solar Energy, 84, 277–288.

Bugutekin, A., 2012. Experimental study of temperature field in a solar chimney plant in Adiyaman. Isi Bilimi ve Teknigi Dergisi. J. Therm. Sci. Technol, 32, 73–80.

Chergui, T., Boualit, A. H., Larbi, S and Bouhdjar, A., 2010. Finite element analysis of laminar flow in solar chimney. Séminaire International sur le Génie Climatique et l'Energétique, SIGCLE.

Chitsomboon, T., 2001. A validated analytical model for flow in solar chimney. International Journal of Renewable Energy Engineering, 3, (2): 339-346.

El-Haroun, A. A., 2012. Performance evaluation of solar chimney power plants in Egypt. Int. J. Pure Appl. Sci. Technol, 13, (2): 49-59.

Ferreira, A. G., Maia, C. B., Valle, R. M and Cortez, M. F. B., 2006. Balanço energético de uma chamine´ solar. Ciência Engenharia, 15, 37–43.

Ghalamchi[1,*], M., Ghalamchi[2], M and Ahanj[3], T., 2013. Numerical simulation for achieving optimum dimensions of a solar chimney power plant. Sustainable Energy, 1, (2): 26-31.

Ghalamchi[a], M., Kasaeian[a,*], A and Ghalamchi[b], M., 2015. Experimental study of geometrical and climate effects on the performance of a small solar chimney. Renewable and Sustainable Energy Reviews, 43, 425–43.

Gannon, A. J and Von Backström, T. W., 2000. Solar chimney cycle analysis with system loss and solar collector performance. Journal of Solar Energy Engineering, Transactions of the ASME, 122, 133-137.

Golder, K., 2003. Combined solar pond and solar chimney. Final year Mechanical Engineering Project. School of Aerospace, Mechanical and Manufacturing Engineering, Bundoora Campus, RMIT University, Melbourne, Australia.

Haaf , W., Friedrich, K., Mayr, G and Schlaich, J., 1983. Solar Chimneys. Part I: Principle and construction of the pilot plant in Manzanares. Int. J. Solar Energy, 2, 3-20.

Haaf, W., 1984. Solar Chimneys. Part II: Preliminary test results from the Manzanares pilot plant. Int. J. Solar Energy, 2, 141-161.

Hartung, C., Marschetzky, H., Link, T., Bauer, M., Künzel, M., Ellwanger, M., Thanh, T. P and Dang, L. N., 2008. (Supervisors: Ruth, J., Gumpp, R.). Solar power plant. <http:// www.archineering.de>

Kalash, S., Naimeh, W., Ajib, S., 2013. Experimental investigation of the solar collector temperature field of a sloped solar updraft power plant prototype. Sol. Energy, 98, 70–77.

Kasaeian, A. B., Heidari, E and Vatan, S. N., 2011. Experimental investigation of climatic effects on the efficiency of a solar chimney pilot power plant. Renew. Sustain. Energy Rev, 15, 5202–5206.

Kasaeian, A., Ghalamchi, M and Ghalamchi, M., 2014. Simulation and optimization of geometric parameters of a solar chimney in Tehran. Energy Convers. Manage, 83, 28–34.

Koonsrisuk, A., Chitsomboon, T., 2009. A single dimensionless variable for solar chimney power plant modeling. Solar Energy 83, (2009): 2136–2143.

Koonsrisuk, A and Chitsomboon, T., 2013. Effects of flow area changes on the potential of solar chimney power plants. Energy, 51, 400-406.

Kröger, D. G and Blaine, D., 1999. Analysis of the driving potential of a solar chimney power plant, Eng. R & D J, 15, 85-94.

Kröger, D. G and Buys, J. D., 1999. Radial flow boundary layer development analysis, R & D J, 15, 95-102.

Larbi, S., Bouhdjar, A., Chergui, T., 2010. Performance analysis of a solar chimney power plant in the southwestern region of Algeria. Renewable and Sustainable Energy Reviews, 14, 470–477.

Maia, C. B., Ferreira, A. G., Valle, R. M and Cortez, M. F. B., 2009b. Analysis of the airflow in a prototype of a solar chimney dryer. Heat Transf. Eng, 30, 393–399.

Mehla, N., Makade, R., Thakur, N. S., 2011. Experimental analysis of a velocity field using variable chimney diameter for solar updraft tower. Int. J. Eng. Sci. Technol, 3, 3167–3171.

Ming, T., Lui, W and Xu, G., 2006. Analytical and numerical investigation of the solar chimney power plant systems. Int. J. Energy Res, 2006; 30: 861-873.

Ming, T., Renaud, K. d., Fanlong, M., Yuan, P and Wei, L., 2013. Chimney Shape numerical study for solar chimney power generating systems. Int. J. Energy Res.

Ministère de l'Environnement et du Développement Durable, Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable, « Troisième rapport sur l'état de l'environnement au Burkina Faso », 2011.

Motsamai, O., Bafetanye, L., Mashaba, K., Kgaswane, O., 2013. Experimental investigation of solar chimney power plant. J. Energy Power Eng, 7, 1980–1984.

Mullet, L., 1987. The solar Chimney- Overall efficiency, design and performance. International Journal of Ambiant Energy, 8, (1): 35-40.

Padki, M. M and Sherif, S. A., 1989. Solar chimney for medium-to-large scale power generation, paper presented at Proceedings of the Manila International symposium on the development and management of energy resources, Manila, Philippines.

Padki, M. M and Sherif, S. A., 1992. A mathematical model for solar chimneys, paper presented at Proceedings of the 1992 International Renewable Energy Conference, in Renewable Energy: Research and Applications, University of Jordan, Faculty of Engineering and Technology, Amman, Jordan, June 22-26, 1992.

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

Pasumarthi, N and Sherif, S. A., 1998b. Experimental and theoretical performance of a demonstration solar chimney model – Part II: experimental and theoretical results and economic analysis. Int. J. Energy Res, 22, 443–461.

Pastohr, H., Kornadt, O and Gürlebeck, K., 2004. Numerical and analytical calculations of the temperature and flow field in the upwind power plant. Int. J. Energy Res, 28, 495–510.

Peng-Hua, G., Jing-Yin, Li and Yuan, Wang., 2014. Numerical simulations of solar chimney power plant with radiation model. Renewable Energy, 62, 24-30.

Putkaradze, V., Vorobieff, P., Mammoli, A and Fathi, N., 2013. Inflatable free-standing flexible solar towers. Solar Energy, 98, 85–98.

Sangi, R., Amidpour, M., Hosseinizadeh, B., 2011. Modeling and numerical simulation of Solar chimney power plants. Solar Energy, 85, 829–838.

Schlaich, J., 1995. The Solar chimney: Electricity from the sun. Edition Axel Menges, Stuttgart Germany.

Schlaich, J., Bergermann, R., Schiel, W and Weinrebe, G., 2005. Design of commercial solar updraft tower systems – Utilization of solar induced convective flows for power systems Journal of Solar Energy Engineering 127, (1): 117-124.

Tayebi, T and Djezzar, M., 2012. Numerical simulation of natural convection in a solar chimney. International Journal Of Renewable Energy Research, 2, (4):

Tayebi, T and Mahfoud, D., 2013. Numerical analysis of flows in a solar chimney power plant with a curved Junction. International Journal of Energy Science (IJES) Volume 3, Issue 4.

Unger, J., 1988. Konvektionsströmungen, B. G. Teubner, ISBN 3-519-03033-0, Stuttgart,

Vahl Davis, G., 1983. Natural convection of air in a square cavity: a Benchmark numerical solution. International Journal of Numerical Methods in Fluids, (3): 249–64.

Xinping, Z., Jiakuan, Y., Bo, X., and Guoxiang, H., 2007. Experimental study of the temperature field in a solar chimney power setup. Applied Thermal engineering, 27, 2044-2050.

Xinping, Z and Yangyang, X., 2014. Solar updraft tower power generation. Solar Energy, xxx, 1–29.

Yan, M. Q., Sherif, S. A., Kridli, G. T., Lee, S. S and Padki, M. M., 1991. "Thermo-fluid analysis of solar chimneys." In Industrial Applications of Fluid Mechanics. Proceedings of the 112th ASME winter annual meeting, Atlanta, GA, pp. 125-130.

Zhou, X. P., Yang, J. K., Xiao, B and Hou, G. X., 2007. Experimental study of the temperature field in a solar chimney power setup. Appl. Therm. Eng, 27, 2044–2050.

Zhou, X., Yang, J., Xiao, B., Hou, G and Xing, F., 2009. Analysis of chimney height for solar chimney power plant. Applied Thermal Engineering, 29, 178- 185.