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Solar Chimney Power Plant-A Review

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Abstract: *Solar technology is the novel technology which uses the natural sunlight to produce electricity. It uses the combination of three simple technologies that is turbine, vertical chimney of some longer height and glass roof collector for absorbing the sun radiations. By proper utilization of this technology the electricity can be generated in abidance and continuously for twenty four hours throughout the year in county like India where there is sunlight almost for nine months in the major part of the country. Much advancement has taken place in this technology for last three decades but the full utilization of this technology has not taken place because of various aspects. This paper presents the critical review of this important technology in the form of the advancements and developments taken place in various parts of the world and analyzes its important aspects.*

Keywords: *chimney technology, greenhouse collector, power plant, Turbine, updraft.*

I. Introduction

The future of this earth and mankind substantially depends on our ability to slow down the population increase in the "Third World" by civilized means. The key is to increase the standard of living, to overcome the inhumane poverty and deprivation. Development requires mechanization and energy. Energy consumption increases proportionally to the gross national product or prosperity while simultaneously the population growth will decrease exponentially. Many developing countries possess hardly any energy sources and their population doubles every 15- 30 years. The result of which are commonly known that is civil wars and fundamentalism. If these developing countries are provided with only a humane and viable minimum of energy the global energy consumption will drastically increase. The sun is the only source which can supply such an enormous amount of energy without an ecological breakdown and without safety hazards and without a rapid depletion of natural resources at the expenses of future generations. Solar chimneys are such devices which can generate energy up to large extent by use of the simple device that is greenhouse collector, Vertical chimney and turbine and produce electricity continuously at minimum cost. It is very necessary to adopt this technology in every part of the world like other conventional sources which we are using regularly.

II. Solar Chimney

The solar chimney power plant combines three familiar components: A solar collector, a solar chimney and power conversion unit (Jorg Schlaich & Wolfgang Schiel, 2000) which include one or several turbine generators. The turbine is driven by air flow produced by buoyancy resulting from greenhouse effect inside the collector (Fig.1). The main function of solar chimney system is to convert solar energy into electrical energy. In the collector, the solar energy will transform into heat energy. The chimney converts the generated heat energy into kinetic energy, which will be transformed into electric energy by using a combination of a wind turbine and a generator. The collector in solar chimney system consists of support matrix, column structure and transparent roof. A large air collector is formed when a transparent glass or plastic roof supported above the ground by column structure and support matrix is stretched out horizontally many meters. The height of the roof slowly increases along a radius from the periphery to the center to guide inward airflow with minimum friction losses. This glass or plastic roof allows the transmission of the shorter wavelength solar radiation but blocks the longer wave length radiation emitted by the ground. As a result, the ground under the roof heats up which in turn heats the air flowing radially above it. The soil surface under the collector cover works as a storage medium, which saves a part of the incoming solar radiation during a day and releases it later during the night. This mechanism is capable of providing a continuous supply of power all year round.

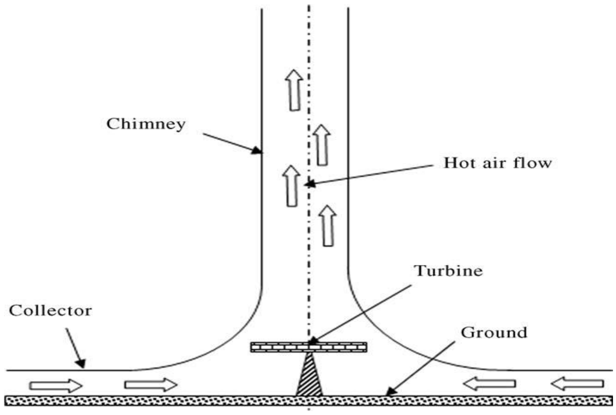

Fig. 1: Schematic illustration of a solar chimney power plant

The chimney situated in the collector center is the actual thermal engine of the solar chimney power plant. The up thrust of the air heated in the collector is proportional to the rise in air temperature flowing in the collector and its volumetric flow rate. Suitable turbines located at the base of chimney convert kinetic energy of the up flowing air inside chimney to mechanical power in the form of rotational energy. The typical solar chimney turbine is of the axial flow type. The principle of operation of these turbines is similar to the turbo generators used in hydroelectric power stations, where the static pressure is converted into mechanical work. The power output achieved is proportional to the product of the volume flow rate and the pressure drop across the turbine. The air flow through the turbine can be regulated by varying the turbine blades pitch angle. This mechanical energy can be converted into electric energy by coupling the turbine to the generator. Solar chimney does not necessarily need direct sunlight. They can exploit a component of the diffused radiation when the sky is cloudy. The lack of system dependence on the natural occurrence of wind, which is intermittent, makes it a very attractive development.

III. Project of Solar Chimney in Various Parts of the World.

3.1 Manzanares Prototype

Detailed theoretical preliminary research and a wide range of wind tunnel experiments led to the establishment of an experimental plant with a peak output of 50 kW on a site made available by the Spanish utility union Electrica Fenosa in Manzanaras about 150 km south of Madrid in 1981-82 (Jorg Schlaich & Wolfgang Schiel, 2000), with funds provided by the German Ministry of Research and Technology. The aim of this research project was to verify, through field measurements, the performance projected from calculations based on theory and to examine the influence of individual components on the plant's output and efficiency under realistic engineering and meteorological conditions. These results show that the components are highly dependable and that the plant as a whole is capable of highly reliable operation. This single global radiation is exploited and the thermodynamic inertia is a characteristic feature of the system. Continuous operation throughout the day is possible and even abrupt fluctuation in energy supply is effectively cushioned, the plant operated continuously even on cloudy days, albeit at reduced output.


Fig. 2. Prototype of Manzanares

3.2 Enviro Mission

Enviro mission is set to build the tallest structure of solar chimney power plant in North America (Reid smith and Lisa Cohn, 2012) with its innovative solar updraft tower design, which provides base load power. The solar updraft tower uses a solar energy collector canopy and a central tower to generate and updraft airflow that drives the rotation of pressure-staged turbines at the base of the tower and generates electricity. Enviro Mission plans to build its first commercial solar updraft tower on public lands in L Paz County, Arizona. If we imagine a sunny day in Arizona where the outside temperature would be 40degrees Celsius, the temperature under the collector would be 80 to 90 degrees Celsius and the temperature at the top of the tower would be 32 degree Celsius. This creates the ideal temperature differential that Enviro Mission desires.

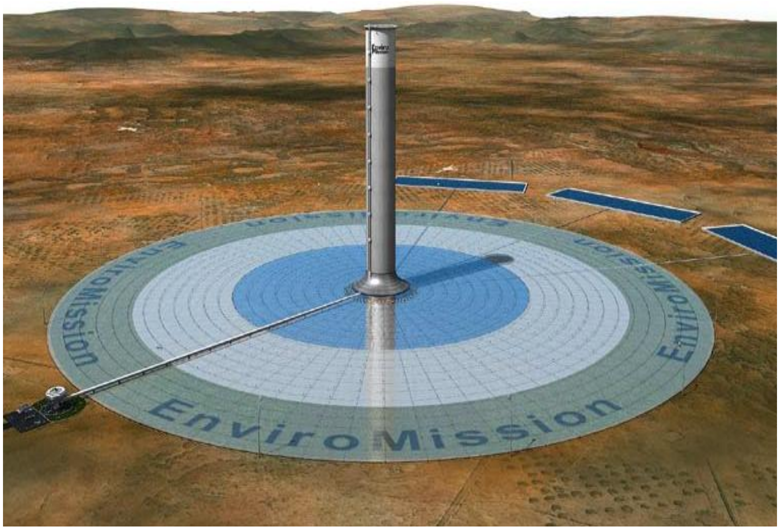

Fig.3 Enviro Mission Arizona USA

3.3 Solar Power Plant in Egypt

To evaluate the performance of solar chimney power plants in some locations in Egypt theoretically and to make an approximation of the quality of the generated electrical energy. A simple mathematical model (El-Haroun, 2012), based on the energy balance was developed to estimate the power output of solar chimneys as well as to observe the effect of various ambient conditions and structural dimensions on the power generation. It was found that the wind speed inside chimney reaches more than 7 times of the value of the free wind speed outside chimney. The solar chimney power plant with 500 m chimney height, 50 m chimney diameter and 3000 m collector diameter is capable of producing yearly between 1.6-1.7 x 10^8 kW hr. in the selected locations in Egypt. Therefore the use of solar chimney power plants in many locations in Egypt will be attractive. It can cover a considerable section of the increasing demand to energy. It can save the use of conventional sources of energy like oil and natural gas and consequently reduces the emissions of harmful gases.

3.4 Solar Technology Nigeria

Solar technology and its necessity in Nigeria were studied (Ngala & Suleiman, 2013). Nigeria which is located between longitude 3^0 and 14^0 East of Greenwich and latitude 4^0 and 14^0 north of equator has about 160 million people and a total land area of 923,768 km^2. Nigeria lies within a high sunshine belt and thus has enormous solar energy potentials. It also describes the economics of power generation by using solar chimney. During operating period the SCPP avoids the CO_2 emissions from coal-fired power plant, which typically emits 0.95 kg of CO_2 per kWh power output. Large amount of carbon credits was therefore obtained for SCPP. In this study the details of SC power technologies are described and the status and development of this technology reviewed including the experimental and theoretical study status, as well as the economics for SC power technology. There are also potentials of citing this technology in Nigeria especially in the semi-arid region with solar sunshine hours of up to 9 hours, solar radiation of 7kW/m^2/day and enormous flat land.

3.5 Solar Chimney in UAE

Analysis of a solar chimney power plant in the Arabian Gulf region of UAE was carried (Mohammad O. Hamdan, 2011). The developed analytical model was used to evaluate the effect of geometric parameters on the solar plant power generation. The analysis showed that chimney height and turbine pressure head are the most important physical variables for the solar chimney design. The study showed that second –law efficiency has no monotonic relation with turbine pressure head. The model shows that second-law efficiency and power harvested increase with the increase of chimney height and/or diameter. The developed model is used to analyze the feasibility of solar chimney power plants for the UAE climate which possesses typical characteristics of the gulf climate. The solar characteristics of the UAE are shown along with characteristic metrological data. A solar chimney power plant with a chimney height of 500 m and a collector roof diameter of 1000 m would produce at least 8 MW of power.

3.6 Solar Chimney in Thailand

The experimental and numerical analysis for the utilization of cool ceiling with roof solar chimney in Thailand was carried out (Sudaporn Chungloo, 2009) to study the benefits of application of solar chimney on the south roof and cool metal ceiling on the north roof through the experiment in a detached building called a controlled cell, and the related numerical model constructed from a computational fluid dynamics (CFD) program. The experimental results are used for calculation on values of heat transfer coefficient of the cool ceiling and evaluation of the mean cooling potential of the combined passive cooling system. The two dimensional numerical models generated by the CFD program use the mean values of wall temperature in the application of solar chimney in the controlled cell as the boundary conditions. The effects of cool ceiling on the temperature, velocity and airflow rate in the controlled cell are investigated through the numerical model in which the north ceiling temperature is reduced by 2-4 ^{0}C from the measured value of 32.8 ^{0}C. The mean cooling potential of the application of combined system is found to be two times higher than the application of the solar chimney. Good agreements between the predicted and experimental results are obtained from the comparison of temperature and volume flow rate at the middle section of the controlled cell. The reduction of north ceiling temperature in the free-convection numerical model shows the decrease of air temperature in the upper region of the room by 0.5-0.7^{0}c from the original value of 33.3^0 C, and the increase of volume flow rate by 12%.

3.7 Solar Chimney Development In China

A heat transfer mode that is used to compare the performance of a conventional solar chimney power plant (CSCPP) and two sloped solar chimney power plant (SSCPPs) with the collector at 30^{0}c and 60^{0}c, respectively was developed in China (Fei Cao Liang Zhao, 2013). The power generation from SCPPs at different latitudes in China is also analyzed. Results indicate that the larger solar collector angle leads to improved performance in winter but results in lower performance in summer. It is found that the optimal collector angle to achieve the maximum power in Lanzhou, China, is around 60^{0}c. Main factors that influence the performance of SCPPs also include the system height and the air thermo physical characteristics. The ground energy loss, reflected solar radiation and kinetic loss at the chimney outlet are the main energy losses in SCPPs. The studies also show SSCPPs are more suitable for height latitude regions in Northwest China, but CSCPPs are suggested to be built in southeastern and eastern parts of China with the combination to the local agriculture.

3.8 Solar Chimney In Botswana

Import of huge proportion of electrical energy from the Southern African Power Pool, and the geographical location and population distribution of Botswana stimulated the need to consider renewable energy as an alternative to imported power. (Clever Ketlogtswe, 2008) a systematic experimental study on a mini-solar chimney system. Particular attention is given to measurements of air velocity, temperature and solar radiation. The result for the selected 5 and 6 clear days of October and November respectively are presented. These results enable the relationship between average insolation, temperature difference and velocity for selected clear days to be discussed.

3.9 Solar Technology in Algeria

The work presented by (Salah Larbi, Adel El Hella, 2013) is related to an energy system analysis based on passive cooling system for dwellings. It consists to solar chimney energy performances determination versus geometrical and environmental considerations. The site located in the southern region of Algeria is chosen for this study according to ambient temperature and solar irradiance technical data availability. The glazing temperature distributions, the chimney mass flow rate, the internal wall temperatures and the air room change per hour (ACH) parameter are presented and discussed. Obtained results show that the maximum of airflow velocity is obtained for small values of the width of the channel because for one fixed flow rate, the velocity increases when the section decreases. The influence of the incident solar radiation is important parameter on energy performances analysis of the chimney and an optimum design between the width of the chimney and the aperture of the absorber wall may exit for increasing ACH parameter. The air gap between the absorber and the glass cover plays an important role in the ventilation rate. The maximum of velocity is located near the main inlet air flow area. The sudden contraction increases the air velocity in this zone due to the vena-contracta effect.

IV. Recent Development In Solar Technologies

4.1 Sloped Solar Updraft Power Plant

A sloped solar updraft power plant was proposed (Shadi Kalasha, Wajih Naimeh, 2014). Designing a solar chimney collector system on sloped surface or suitable hills has two major advantages. First, if the collector slope is optimized, the solar radiation received by the collector system may be improved to a satisfactory level for a year round operation. Second, a slope surface constitutes a natural chimney; therefore the chimney height standing above the collector height may be reduced considerably, thus reducing civil engineering problems and cost. This new design is called the sloped solar updraft power plant (SSUPP). The monthly average values of the collector outlet, chimney inlet, ambient temperature and solar radiation were recorded and plotted to investigate the prototype performance a year round. The investigations show that the temperature difference between the ambient temperature and the chimney inlet temperature is almost the same in winter and summer. This result is due to optimizing the solar collector which was inclined in the same angle of the latitude in the prototype location. The results show a direct impact of both solar radiation and ambient temperature on the collector outlet air temperature.

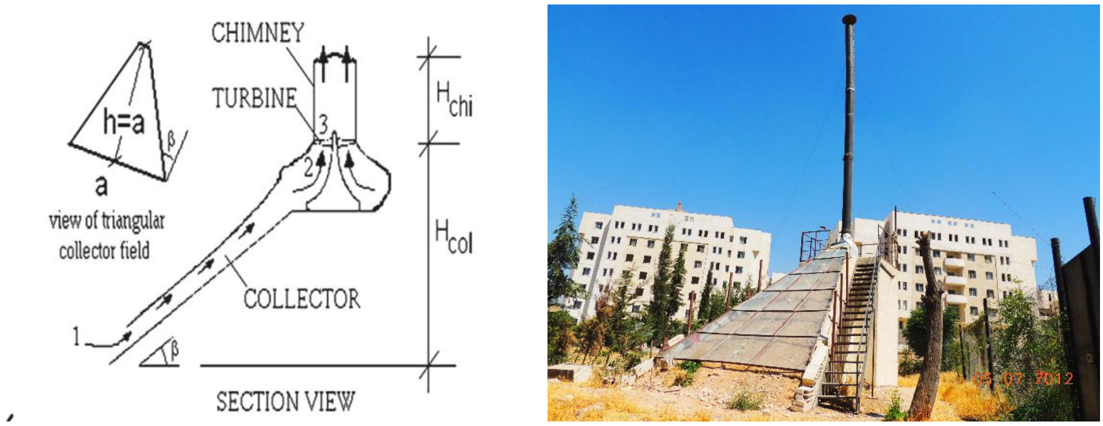

Fig.4 Systems in sloped surface at high latitudes

4.2 Counter Rotating Turbines

Two counter rotating turbines, one with inlet guide vanes, the other without, are compared to a single-runner system. The design and off-design performances are weighed against in three different solar chimney plant sizes. It was shown (Denantes, 2006) that the counter- rotating turbines without guide vanes have lower design efficiency and a higher off-design performance than a single-runner turbine. Based on the output torque versus power for various turbine layouts, advantageous operational conditions of counter rotating turbines are demonstrated. The counter-rotating turbines offer their best efficiency at higher load factors than the single-runner turbines. The main advantage of this turbine type in the solar chimney systems is its off-design performance. By considering that solar chimney power plant will be operated most of the time at a solar intensity of less than $800W/m^2$, the counter rotating turbine systems will be advantageous with respect to single-runner systems from the efficiency point of view as well as annual electric energy production. One other advantage is the reduced torque on each axis compared to the single-runner turbine.

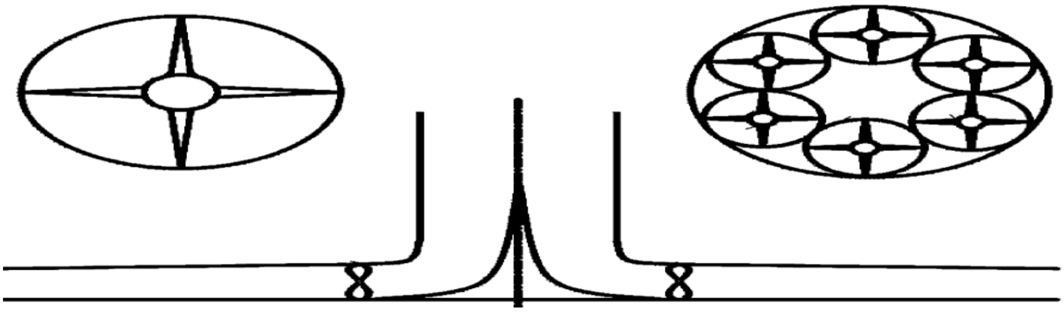

Fig.5 Counter Rotating Turbines

4.3 Asphalt Concrete Solar Collector

Asphalt concrete can absorb a considerable amount of the incident solar radiation. For this reason asphalt roads could be used as solar collector. There have been different attempts to achieve this goal. All of them have been done by integrating pipes conducting liquid, through the structure of the asphalt concrete. The problem of this system is that all pipes need to be interconnected; if one is broken, the liquid will come out and damage the asphalt concrete. To overcome these limitations (Alvaro Garcia, 2014) an alternative has proposed that is parallel air conduits, where air can circulate will be integrated in the pavement structure. The idea is to connect these artificial pore volumes in the pavement to an updraft or to a downdraft chimney. Differences of temperature between the pavement and the environment can be used to create an air flow, which would allow wind turbines to produce an amount of energy and that would cool the pavement down in summer or even warm it up in winter. To demonstrate that this is possible, an asphalt concrete prototype has been created and basics calculations on the parameters affecting the system have been done. It has been found that different temperatures, volumes of air inside the asphalt and the difference of temperature between the asphalt concrete and the environment are critical to maximize the air flow through the pavement. Moreover, it has been found that this system can be also used to reduce the heat island effect.

4.4 Structural Stability of Concrete Wind Turbines and Solar Towers Exposed to Dynamic Wind Action

The solar chimney operates like a hydroelectric power plant, but instead of water, it uses a hot air. This is particularly useful in arid area, which is plentiful in Africa, even south of Sahara. It comprises a transparent roof collector, a central chimney tower and one or more turbo generators at the base. Beneath the collector, (Reinhard Hartea, 2007) a large, circular glass roof, air is heated. Through the coinciding change in air pressure, the air moves radially towards the centre, where it enters the tower, which creates an up-draught. By this suction effect, hot air is drawn in from the collector and as it rises up the chimney, it flows through one large turbine or numerous smaller turbines, the preferred option yet to be determined. These turbines are linked to conventional generators, whereby electricity is generated. The output of the solar chimney is proportional to its size. The scale of a 1000-1500m tall, 160m diameter chimney tower and a glass roof collector of diameter 4-7 km is proposed to produce an output of 200- 400MW.

4.5 Reinforce Concrete (RC) Chimneys With Fiberglass Reinforce Plastic(FRP)

A simple method to calculate fire duration and flue gas temperatures for reinforced concrete (RC) chimneys with fiberglass reinforced plastic (FRP) liners based on experimentally determined burning characteristics of the liner material was proposed (Artemis Agelaridou-Twohig, 2014). Implementation of the method to calculate fire durations and the transient heat transfer conditions is demonstrated for single and four liner chimney. A parametric study is carried out for chimney designs and geometries ranging from 100 m to 300 m in height and 7 m to 40m in diameter, with 1-4 liners and varying opening configuration. The results are used to identify a limited number of cases for which the RC chimney undergoes the most extreme reduction in its post-fire residual strength. Analytical estimations of the chimney residual strength after the fire are obtained using a method established based on the procedure outlined in the American Concrete Institute (ACI) 307 standard for chimney strength calculations. Calculations for a series of critical configuration of RC chimneys, with FRP liner geometries within the practical design limits detailed. This shows that the post-fire structural capacity of the chimney would not lead to catastrophic failures especially because the chimney is not expected to see other high design lateral loads such as wind or earthquake simultaneously.

4.6 Constructal Geometry of A Solar Chimney

The study to describe the constructal-theory search for the geometry of a solar chimney was conducted. The objective of (A.Koonsrisuk, S. lorente, 2010) was to increase the power production over the area occupied by the plant. The ratio height/radius, maximum mass flow rate and maximum power under the constraints of a fixed area and volume are determined. The power generated per unit of land area is proportional to the length scale of the power plant. The analysis is validated by a detailed mathematical model. Pressure losses are reported in terms of the dimensionless length scale of the system and are illustrated graphically. They indicate that the pressure drop at the collector inlet and at the transition section between the collector and chimney are negligible and the friction loss in the collector can be neglected when the svelteness of the entire flow architecture is greater than approximately 6.

4.7 Air Energy Available In Solar Chimney

Solar chimney is defined as low temperature solar thermal power plants, which use the atmospheric air as a working fluid, where only one part of the thermodynamic cycle within the plant is utilized. The available work potential that atmospheric air acquires while passing through the collector has been determined and analyzed. The dependence of the work potential on the air flowing into the air collector from the heat gained inside the collector, air humidity and atmospheric pressure as a function of elevation are determined. Various collector types using dry and humid air have been analyzed (N. Nini, 2006). The influence of various chimney heights on the air work potential was established. The possibly higher utilization factors of the available hot air work potential without the use of high solid chimneys are discussed. It has been shown that the vortex motion flowing downstream of the turbine can be maintained under pressure and can possibly take over the role of the solid structure chimney. Thus a part of the available energy potential acquired in the collector would be used to maintain the vortex flow in the air column above the ground level turbine. Basic conditions for the maintenance of such a vortex flow are described and compared to the tornado phenomenon.

4.8 Turbine Layout of Solar Chimney Power Plant

The power conversion unit of a large solar chimney power plant converts the fluid power, first into mechanical power and then into electrical power (Thomas Peter Fluri, 2008). A tool is developed to determine the layout and the number of turbines of the solar chimney power conversion unit providing the lowest cost of electricity. An analytical turbine model is developed. Several modeling approaches and the performance of single rotor and counter rotating turbine layouts are compared. Preliminary turbine designs are investigated, experimentally and numerically. The main aim of the experimental investigation is to verify the applicability of the loss model used in the analytical turbine model. The aim of the numerical investigation is to evaluate a commercial software package as a tool in context with solar chimney turbines. For each component of the power conversion unit and analytical performance model is introduced. Using these models, the single vertical axis, multiple vertical axis and multiple horizontal axis turbine configurations are compared from an efficiency and energy yield point of view and the impact of the various losses on the overall performance is highlighted. A detailed cost model for the power conversion unit is also presented. To optimize for cost of electricity this cost model is then linked to the performance models and the resulting optimization scheme is applied to several plant configurations.

4.9 Solar Chimney and Linked Renewable Energy Conversion Devices

A solar tower constituted (Denis Bonnelle, 2004) from a wide circular glass collector and a1 km high chimney, where hot air flows upwards and drives some turbines; and a downwards tower where dry air is cooled down by the evaporation of sprayed water droplets. Each of both projects is born by a competent team, but their credibility is undermined by competitors, whose publication include serious basic errors. Some technical improvements are proposed for the solar tower, with the goal to be able to design a larger solar collector and a higher tower and boost the global efficiency. Possible effects on the global biosphere circulations are described, in order to find the most neutral or beneficent solution, e.g. a combination of energy towers and bigger towers having many common features with solar chimney.

4.10 Flows in Solar Chimney for an Optimal Design Purpose

Diversified approaches were used to find ways to improve the efficiency of a solar chimney (Atit Koonsrisuk, 2009). The approaches can be divided into categories of theoretical, experimental and numerical methodologies. He describes the objectives, the problem and rational and the methodology of the research. Dimensional analysis was used in to determine the scaling law for the flow in solar chimney systems and the results obtained were verified by using the computational Fluid Dynamics technique (CFD). Inspection of the mathematical model suggests the flow area ratio that can increase the plant performance. To support the idea, the mathematical analysis was carried out and then proved by CFD. The mathematical model of the system with a turbine was developed in to evaluate the plant performance. He shows the experimental performance of four small-scale physical models. Finally the method of constructal design was used to search for a better design of the flow system.

4.11 Control of Large-Scale Solar Chimney Power Plant

To control large scale solar power plant based on a reference location near Sishen in South Africa and a so called reference solar chimney power plant with a 5000 m collector diameter and a 1000 m high, 210 m diameter chimney. The numerical simulation model is refined and used to perform a sensitivity analysis (Johnnes Petrus, 2007) on the most prominent operating and technical plant specifications. Thermo-economically optimal plant configurations were established from simulation results and calculations according to an approximate plant cost model. The effects of ambient wind, temperature lapse rates and nocturnal temperature inversions on plant performance are examined. Various new technologies are investigated for the purpose of controlling plant output according to specific demand patterns. The incorporation of vegetation under the collector roof of the plant and the influence there of on plant performance is also explored.

Results indicate that, through the modification of the collector roof reflectance, collector roof emissivity, ground surface absortivity or ground surface emissivity; major improvements on plant performance are possible. Introducing thermal insulation or double glazing of the collector roof also facilitates substantial enhancements on plant yield. Simulations predict a notable sensitivity to the ground surface absortivity value, while variable atmospheric temperature lapse rates and windy ambient conditions may impair plant performance significantly. Furthermore, sand is found to be unsuitable as plant ground type and thermo economically optimal solar chimney plant dimensions are determined to be generally larger than plant dimensions employed in previous studies. Good dynamics control of solar chimney power output is established, suggesting that a solar chimney power plant can be implemented as a base or peak load electricity generating facility.

4.12 Floating Solar Chimney Technology

Floating solar chimney (FSC) is a low cost alternative of the concrete solar chimney. The floating solar chimney, as a lighter than air structure, can be raised anywhere and its cost is as low as 2% of the cost of the respective concrete chimney. The approach (Papageogiou, 2011) includes a low cost greenhouse that can be used in FSC technology, which is also a low cost alternative to the usual glass roofed circular greenhouse related to the concrete chimney. This plastic covered low cost greenhouse could solve also the ingress of dust, which is a problem that could be a serious obstacle in desert installations of the FSC technology. Furthermore according to the construction cost and the electricity generation figures we present a scale analysis of the FSC technology. Even with moderate height FSC structures of 650m, is possible the direct production cost to be approximately 45USD /MWh. The unused mid-latitude desert or semi desert lands of high solar radiation in many countries in all continents can be used for large scale application of floating solar chimney technology securing sustainability and mitigating global warming effects.

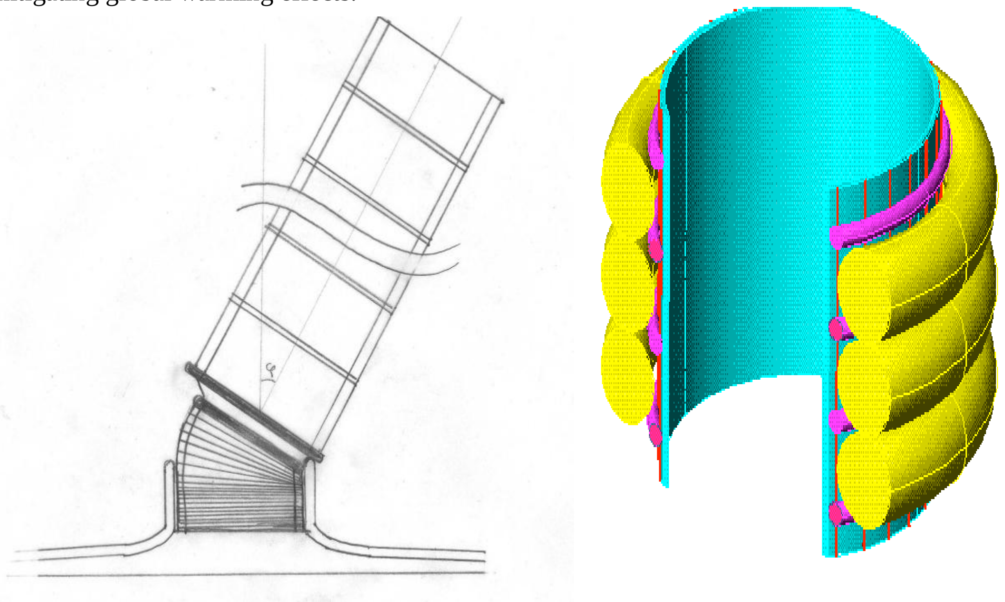

Fig.6- Floating Solar chimney Technology

V. Theoretical And Experimental Studies

Various theoretical and experimental studies are carried out after the successful testing of Manzanares France prototype in 1982. Size and configuration of solar chimney are different according to different regions. Few of these studies are stated as below.

5.1 Thermal and Technical Analyses of Solar Chimneys

An analysis for the solar chimney has been developed (Bernardes, 2003), aimed particularly at a comprehensive analytical and numerical model, which describes the performance of solar chimneys. This model was developed to estimate power output of solar chimney as well as to examine the effect of various ambient conditions and structural dimensions on the power output. Results from the mathematical model were compared with experimental results and the model was further used to predict the performance characteristics of large scale commercial solar chimneys. The results show that the height of chimney, factor of pressure drop at the turbine, the diameter and the optical properties of the collector are important parameters for the design of solar chimneys. The objective of this study was to evaluate the solar chimney performance theoretically. A mathematical model was developed to estimate the temperature and power output of solar chimney as well as to examine the effect of various construction conditions on the power output. The mathematical model was validated with the experimental data from the prototype in Manzanares. The power output can be increased by increasing the chimney height, collector area and the transmittance of the collector. The maximum power can be reached when the factor of pressure drop at the turbine is equal to approximately 0.97. Other parameters such as ground heat penetration coefficient distance between absorber and ground, double cover area, water-storage system area and thickness presented no significant variations on the energy output, but on power output vs. time.

5.2 Maximum Fluid Power Conditions in Solar Chimney Power Plant

The objective of the study (Von Theodor, W.Backstrom, Thomas P.fluri, 2006) was to investigate analytically the validity and applicability of the assumption that, for maximum fluid power, the optimum ratio of turbine pressure drop to pressure potential. The study developed two analyses for finding the optimal ratio of turbine pressure drop to available pressure drop in a solar chimney power plant for maximum fluid power. It was shown that the constant pressure potential assumption may lead to appreciable under estimation of the performance of a solar chimney power plant, when compared to the model using a basic model for the solar collector.

5.3 Mathematical Modeling of Solar Chimney Power Plant

A solar collector, chimney and turbine are modeled together theoretically (Atit Koonsrisuk, Tawit Chitsomboom, 2013) and the iteration techniques are carried out to solve the resulting mathematical model. Results are validated by measurements from an actual physical plant. Moreover the model is employed to predict the performance characteristics of large scale commercial solar chimney, indicating that the plant size, the factor of pressure drop at the turbine and solar heat flux are important parameters for performance enhancement. In addition the study proposes that the most suitable plant, affordable by local government standards to respond to the electricity demand of a typical village in Thailand, is the one with a collector radius and chimney height of 200 m and 400m, respectively. Furthermore, it is shown that the optimum ration between the turbine extraction pressure and the available driving pressure for the proposed plant is approximately 0.84. A simple method to evaluate the turbine power output for solar chimney systems is also proposed in the study using dimensional analysis.

5.4 Solar Updraft Power Plants: Engineering Structures for Sustainable Energy Generation

This present (Reinhard Harte, Tudiger Hoffer, Wilfried b. Kratzig, 2013), the working principles of solar updraft power plants; followed by explaining climatic and wind-technologic design assumptions. Then the central solar updraft chimney and the power tower are treated in more detail: a thin ring-stiffened RC shell of extreme height, forming the utmost structural challenge of such plants. This part is followed by technical requirements for the collector constructions, by far the largest glass-covered areas ever built, and of the wind loading on the glazing. Then, further design aspects are extracted by the durability requirements for at least 100 years of operation in extreme desert climates. The paper closes with some cost estimates for the generated electricity. This present manuscript has concentrated their own cost-estimations on optimized smaller plants with 500m and 750 m of chimney heights.

5.5 Solar Chimney Model with Uniform Wall Heat Flux

Experiments are carried out using an experimental solar chimney (Z.D. Chena, P.Bandopadhayay, J.Halldorsson, 2003) model with uniform heat flux on one chimney wall with a variable chimney gap-to-height ratio between 1:15 and 2:5 and different heat flux and inclination angles. Results showed that a maximum air flow rate was achieved at an inclination angle around 45^0 for a 200 mm gap and 1:5 m high chimney and the air flow rate is about 45% higher than that for a vertical chimney at otherwise identical conditions. It was found that the prediction method available in the literature can substantially over predict the airflow rate for the chimney geometry investigated in this work, especially for vertical chimneys with large gaps. The main reason for the over prediction of air flow rate was shown due to the underestimation of the pressure losses at the chimney outlet by using loss coefficients obtained for normal forced flows.

5.6 Behavior of the Airflow In A Solar Chimney

An analytical and numerical study of the unsteady airflow inside a solar chimney was performed by (Cristiana B. Maia, Andre G. Ferreira, Ramon M. Valle, 2009). The conservation and transport equations that describe the flow were modeled and solved numerically using the finite volumes technique in generalized coordinates. The numerical results were physically validated through comparison with the experimental data. The developed model was used for airflow simulation in solar chimneys with operational and geometric configurations different from those found in the experimental prototype. Analysis showed that the height and diameter of the tower are the most important physical variables for solar chimney design.

5.7 Enhanced Heat Transfer in Inclined Solar Chimneys

Numerical simulations are carried out to analyze the mechanism of natural convection inside the inclined solar Chimneys incorporating an electro hydrodynamic effect induced from wire electrodes (Nat Kasayapanand, 2007). The volume flow rate enhancement of fluid inside the solar chimney increases to the maximum point but reduces when the number of electrodes is sufficiently high due to pressure drop. The heat transfer enhancement decreases to the minimum point at the intermediate number of electrodes and significantly increases at high number of electrodes. The inclined angle at 600 performs maximum volume flow rate and also heat transfer due to the highest temperature gradient along hot plate. Moreover, all chimney aspect ratios can be obtained by the optimization between augmented heat transfer and power consumption from a suitable electrode distance ratio. Thus, for high efficiency and economy design, it should be compromised among all concerning parameters.

5.8 Optimal Ratio of Pressure Drop Across the Turbine In Solar Chimney Power Plants

A simplified analytical approach for evaluating the factor of turbine pressure drop in solar chimney power plants is presented (S. Nizetic a, B. Klarin, 2010). This characteristic factor (or pressure drop ratio in turbines, according to the total pressure drop in the chimney) is important because it is related to the output power. The determined factor (or ratio) values of the turbine pressure drop are found to be within a value range consistent with other studies. It was concluded that for solar chimney power plants, turbine pressure drop factors are in the range of 0.8 -0.9. This simplified analytical approach is useful for preliminary analysis and fast evaluation of the potential of solar chimney power plants. In this work, a simplified analytical approach for the evaluation of the optimal pressure drop ratio in solar chimney power plants is presented. The approach is based on a simplified thermodynamic analysis of the overall SC cycle. It is estimated that the ratio depends on two parameters: the air flow velocity at the solar chimney inlet. It is also shown that changes in either parameters result in similar changes to the ratio, this ratio value is in accordance with values provided by other authors. Hence, this proposed simplified analytical approach demonstrates that in solar chimney power plants, the turbine pressure drop factor varies from 0.8 to 0.9. Therefore, it can be concluded that the proposed simplified approach is reliable and useful for a preliminary power estimation of solar chimney power plants for a given conditions.

5.9 Solar Chimney Simulation and Experiment

The use of solar chimneys in buildings is one way to increment natural ventilation and as a consequence, to improve indoor air quality (Clito Afonso, Armando Oliveira, 2000). They are similar to conventional chimneys except that the south wall is replaced by a glazing. In order to compare the behavior of a solar chimney with a conventional one, one of each was built in Porto. Results of measurements carried out in both chimneys are shown in this paper, as well as results of a thermal model specially developed for simulating solar chimneys, taking into account the wind effect. It was concluded that there is a significant increase in ventilation rate with solar chimneys and that the thermal model predicts with good accuracy the measurements carried out. Due to the variable nature of wind, the design of a solar chimney can be done without considering the wind effect, which will underestimate the real ventilation rates. In the design process, two parameters can be changed for satisfying the needed average flow rate: chimney section and chimney height; the average flow rate changes linearly with chimney section; for a given solar collection area, it is better to have a larger chimney width and a smaller height.

5.10 Solar Chimney Power Plant Systems Coupled with Turbine

Numerical simulations have been carried out on the solar chimney power plant systems coupled with turbine (Ming Tingzhena, Liu Weia, Xu Guolinga, Xiong Yanbin, 2008). The whole system has been divided into three regions : the collector, the chimney and the turbine and the mathematical models of heat transfer and flow have been set up for these regions. Using the Spanish prototype as practical example, numerical simulation results for the prototype with a 3-blade turbine show that the maximum power output of the system is a little higher than 50kW. Furthermore, the effect of the turbine rotational speed on the chimney outlet parameters has been analyzed which shows the validity of the numerical method advanced by the author. Thereafter, design and simulation of a MW-graded solar chimney power plant system with a 5-blade turbine have been presented and the numerical simulation results show that the power output and turbine efficiency are 10MW and 50%, respectively, which presents a reference to the design of the large-scale solar chimney power plant systems.

5.11 Solar Chimney and Building Ventilation

CFD was used to investigate the performance of a solar chimney. It was found that varying the slope of the chimney resulted in variations in performance, as measured by the airflow rate through the chimney (D.J. Harris, N.Helwig, 2007). The optimum slope –angle for maximum flow is 67.5m from the horizontal, giving an average benefit of 11% increase in flow rate in comparison with that for a vertical chimney. This gives an improved performance in cooling and ventilating the building and reduces the risk of overheating. Application of low-emissivity finishes to the wall offers an additional way of improving performance, giving approximately a further 10% improvement at that angle. The addition of double glazing gave a slight improvement in performance, but it was not significant enough to be cost effective. Although the effect of wind on the flow rates has not been investigated here, it would be an interesting avenue for future research. With roof angles less than

23^0 from the horizontal, the effect of wind always is to increase the stack suction pressure. With roof angles greater than this, wind direction plays a part in determining whether the stack pressure is increased or decreased.

5.12 A Comprehensive Approach to Design and Improve a Solar Chimney Power Plant

The objective of this paper was to present a comprehensive analysis including analytical and numerical models which were developed to predict the performance of a solar chimney power plant in Kerman, Iran. The numerical model results including air temperature, velocity and electrical power output were validated by comparing with experimental data of the Manzanares prototype power plant. Also the mathematical model was verified with the practical output of the Kerman pilot plant. Also in this paper novel approach to evaluate the influence of the site altitude on the potential of solar chimney power plants was presented and thereby a coefficient called altitude effectiveness was defined using Manzanares prototype geometrical parameters in different site altitudes. The development model was applied to improve the performance of a solar chimney pilot power plant built in Kerman, Iran. Based on an approximate cost model, the thermo-economic optimal configurations of the pilot power plant were illustrated; and also it was found that the chimney diameter was the most important structural dimension to improve the performance of this pilot power plant.

5.13 Simulating Home Cooling Load Reductions for a Novel Opaque Roof Solar Chimney Configuration

The roof solar chimney (RCS) is a low cost passive ventilation technique for reducing the energy consumption for cooling buildings (Justin DeBlois, Melossa Bilec, Laura Schaefer, 2013). This study examines the performance and level of energy savings by simulating a detached home in four climates with RSC, cross-ventilation and standard ventilation strategies. Each case was simulated in ESP –r for baseline and high efficiency construction, detached homes with a single story, three bedrooms a 189 m^2 floor plan and high thermal mass constructions. Photovoltaic panels were integrated into the surface of the solar chimney on the south-facing roof to improve the RSC performance with their absorptive properties, and provide cooling to the reverse of the panels with the ventilation airflow. To form the RSC, a gap under the external layer of the roof allowed air-flow from the interior of the house to a plenum in the peak of the attic with vents to the outside. Cross ventilation was aided with openings in the interior walls allowing flow between rooms. The ventilation gap was modeled by discretizing the RSC into 12 sections and calibrating the air-flow and convection coefficients with corresponding computational fluid dynamics models. The results indicate that the ventilated roof provides free cooling and natural ventilation in all climates and seasons tested. Flow was caused more by the stack effect rather than through natural convection and the solar chimney effect. Cross ventilation reduced cooling load by approximately 50% over the baseline and the ventilated roof by up to another 80%. Both advanced natural ventilation approach reduced cooling load by more than the green envelope and efficiency practices in three of the four climates. The natural ventilation techniques were proportionally as effective in reducing load in a high efficiency home as in the base case home.

5.14 Effects of Collector Radius and Chimney Height on Power Output of a Solar Chimney Power Plant with Turbines

A comprehensive theoretical model has been developed by (Jing-yin Li, Peng-hua Guo, 2012) taking account of the detailed thermal equilibrium equations in the collector, the system driving force and the flow losses based on existing experimental data or formulas. The theoretical model has been validated by the experimental data of the Spanish prototype. It concludes that the installation of the turbine in the SCPP system will considerably reduce the power output of the SCPP, compared with the unloaded condition. There exists a maximum power output for a given SCPP at a certain solar radiation. The operating points of the turbine and the SCPP system are recommended to be chosen on the left-hand-side of the maximum power line, to obtain a longer continuous power output. There is a limitation on the maximum collector radius, beyond which the attainable power output of the SCPP increases very slowly. On the contrary, no such limitation placed on the chimney height exists, in light of the current construction technology.

5.15 A Hybrid Cooling Tower and a Solar Chimney Concept

An innovative concept for recombining a thermal steam power plant dry cooling tower with a solar chimney is introduced (Arash Zandian, Mehdi Ashjaee, 2013). A model has been designed using the typical dimensions and properties of Shahid Rajaee 250 MW steam power plant and the Manzanaras solar chimney. A numerical simulation for the hybrid system including solar collectors, cooling tower radiators and wind turbine is then developed. The effects of environmental temperatures and solar irradiations on the generated turbine power have been illustrated. At the end, the effects of chimney diameter on the hybrid system (HCTSC) power output and the total fossil fuel power plant efficiency have been researched. The results indicate an over ten times increase in output power of the hybrid system compared to experimental results for the conventional solar chimney power plant prototype with similar geometrical dimensions in Manzanares, for the same environmental conditions. In addition, with increase of chimney diameter the power generation can reach to MW-graded power output without the necessity of building huge individual solar chimney power plants. The results show a maximum of 3 MW power output from the HCTSC system that results in 0.37% increase in the thermal efficiency of the Shahid Rajaee 250 MW fossil fuel power plant, when the chimney diameter is 50 m.

5.16 Numerical Simulations of Solar Chimney Power Plant with Radiation Model

A three dimensional numerical approach incorporating the radiation, solar load and turbines models proposed, was first verified by the experimental data of the Spanish prototype (Jing-yin Li, Yuan Wang , 2014). It then was used to investigate the effects of solar radiation, turbine pressure drop and ambient temperature on system performance in detail. Simulation results reveal that the radiation model is essential in preventing the overestimation of energy absorbed by the solar chimney power plant. The predictions of the maximum turbine pressure drop with the radiation model are more consistent with the experimental data than those neglecting the radiation heat transfer inside the collector. In addition, the variation of ambient temperature has little impact on air temperature rise despite its effect on air velocity. The power output of the SCPP within the common diurnal temperature range was also found to be insensitive to ambient temperature. In simulating the performance of the SCPP system, the radiation, solar load and turbine models were incorporated into a 3-D numerical computation for the first time. The adopted numerical approach was first validated by the experimental data of the Spanish prototype and then was used to investigate the effects of solar radiation, turbine pressure drop and ambient temperature on system performance, the conclusions that can be drawn are that the radiation heat transfer is an important factor in the heat transfer process inside the SCPP and should be considered in the numerical simulation. Otherwise, heat losses would be dramatically underestimated. The effects of solar radiation and turbine pressure drop on SCPP performance are considerable. Furthermore the proposed numerical approach could provide a reasonable prediction of the maximum turbine pressure drop at a certain solar radiation, which is an important factor in the determination of turbine design point and operation range. The variation of ambient temperature has a negligible effect on air temperature rise, but has an evident effect on air velocity. The SCPP power output within the common diurnal temperature range is found to be insensitive to ambient temperature.

5.17 Performance of A Coupled Cooling System with Earth-To-Air Heat Exchanger and Solar Chimney

To utilize the solar energy and geothermal for free cooling (Haorong Li, Yuebin Yu, Fuxin Niu, Michel Shafik, 2014) devised a coupled passive energy system with a solar collector enhanced solar chimney and an earth-to-air heat exchanger. Research has been conducted on the coupled system at the solar energy research test facility to further investigate the performance of the coupled system. Experiments and analysis have been carried out in order to evaluate the cooling capacity that the coupled system can provide to the test room and the impact factor. In the test, the coupled system was operated in a natural passive mode. Without any mechanical component, the air was driven into the building by means of the passive solar energy and the stack effect. During the natural airflow test, the coupled system was able to maintain the indoor thermal environmental comfort conditions at a favourable range that complied with ASHRAE standard for thermal comfort. The indoor air temperature was maintained at a range of 21.3-25.1^{0}C, while the indoor humidity ratio was maintained at a range of 50-78%. The coupled system provided an acceptable amount of cooling capacity during the natural airflow test in 2008. The EAHE maximum cooling capacity during that test was 3308W. While the coupled system maximum cooling capacity was 2582 W, which almost covered the building design cooling load. During the natural airflow mode, it was found that the increase in the outdoor air temperature and solar radiation increases the solar chimney natural draft and the amount of airflow to the building, which in turn increase the amount of cooling capacity provided to the building.

5.18 Three-Dimensional CFD Analysis for Simulating the Greenhouse Effect in Solar Chimney Power Plan

The objective of this paper (Ehsan Gholamalizadeh, Man-Hoe Kim, 2014) was to analyse the buoyancy-driven flow field and heat transfer inside the solar chimney power plant, simulating the greenhouse effect. In this paper a three dimensional unsteady CFD model to analyze the solar chimney power plant system was developed. In order to simulate the turbulent flow inside the system the RNG ke-ε model was used. A two band model for short and long wavelength radiation was implemented to simulate the greenhouse effect in the system. In order to solve the radiative transfer equation the discrete ordinates method was used. To calculate radiation effects from the sun's rays, the solar load model's ray tracing algorithm was employed, which appears as a source term in the energy equation. The model provided good agreement with experimental measurements of the Manzanares power plant. The analysis showed that imulating the greenhouse effect through the collector has a significant effect on predicted characteristics of the flow and heat transfer in the system. Based on the results, the effects of solar insolation and pressure drop across the turbine on the distributions of the velocity and temperature were considered, using geometry parameters of the Manzanares power plant. Also, enthalpy rise through the collector and energy loss from the chimney outlet for 1-band and two- band radiation model are compares in different solar insolations. Furthermore, temperature profile of the ground surface of the system is illustrated. It can be concluded that simulating the greenhouse effect has a significant effect to accurately describe all the phenomena occurring in SCPP systems.

5.19 Numerical Analysis on an Industrial-Scaled Solar Updraft Power Plant System with Ambient Crosswind

Existing research (Wenquing Shen, Tingzhen Ming, Tan Ding, Yongjia Wu, 2014) indicated that the ambient crosswind (ACW) has very complex influences on the SUPPS both through the chimney outlet and collector inlet and demonstrated by numerical analysis from the Spanish prototype. But what influence exert ACW through chimney outlet and collector inlet independently on the overall performance of SUPPS is still unclear. In this research, two geometrical models are instructed for numerical simulation on industrial-scale SUPPS in vicinity of 10 MW. In model 1, ACW acts on both chimney outlet and collector inlet; in model 2, ACW acts only on the chimney outlet. Fluid flow, heat transfer and power output performances of SUPPS are investigated and discussed. It is found that, the negative effect of ACW only occurs at the collector inlet, with cold ambient air into the collector resulting in changing of fluid distribution and deterioration of buoyant driving force, whereas the positive effect occurs at the chimney outlet, with strong ACW passing by the chimney outlet causing entrainment of buoyant airflow within the chimney outlet. To avoid deterioration and to improve the overall performance of SUPPS, effective measures can be taken to prevent ACW from entering the collector inlet and also to induce beneficial effects of high altitude strong ACW blowing across the chimney outlet.

5.20 Thermal Management of a Symmetrically Heated Channel Chimney System

A parametric study on a channel-chimney system was accomplished (Assunta Andrezzi, Bernardo Buonomo, Oronzio Manca, 2009). In this numerical investigation in order to evaluate some geometric optimal, configurations in terms of significant dimensionless geometric and thermal parameters. In the system, the channel walls are symmetrically heated at uniform heat flux. Temperature wall profiles, as a function of axial coordinate, suggested the evaluation of thermal performances of the channel-chimney system in terms of maximum wall temperatures for different expansion ratios, as a function of the chimney aspect ratio. For considered Rayleigh number values, the difference between the highest and the lowest maximum wall temperature increasing channel aspect ratio. This behavior was as greater as the extension ratio was. These differences decreased significantly for the highest Rayleigh number value. Correlations for dimensionless mass flow rate, maximum wall temperature and average Nusselt numbers, in terms of Rayleigh number and dimensionless geometrical parameters, were also proposed.

5.21 Study of the Natural Connection Phenomena inside a Wall Solar Chimney with One Wall Adiabatic and One Wall under a Heat

This work (Evangellos Bacharoudis, Michalis Gr. Vrachopoulos, Maria K. Koukou, 2007) focuses on the study of the thermo fluid phenomena occurring inside wall solar chimney that have been constructed and put at each wall and orientation of a small-scale test room. A numerical investigation of the buoyancy-driven flow field and heat transfer that take place inside the wall solar chimney is performed. The governing elliptic equations are solved in a two-dimensional domain using a control volume method. The procedure is general and can be applied for the simulation of solar chimneys of different aspects ratios and conditions. For the numerical simulation of the turbulent flow inside the wall solar chimney six turbulence models have been tested: the standard k-e model, the RNG k-e model, the realizable k-e model, the Reynolds stress model and two low-Reynolds models. It is concluded that the use of the k-e models and the use of the Abid Low-Re model assures the prediction of realistic velocity and temperature profiles as expected by theory. As the realizable k-e model is likely to provide superior performance for flows boundary layers under strong adverse pressure gradients, the later has been selected to be used in the simulations. Furthermore, this selection is confirmed from the comparison with the experimental results. Simulation results also show that the model predicts realistically the system behavior for various environmental conditions while they support the evaluation of the air mass flow rate that can be achieved through this system and the turbulence effects.

5.22 Analysis of Chimney Height for Solar Chimney Power Plant

Current in solar chimney power plant (xinping zhou, jiakuan yang, bo xiao, guoxiang hou, 2009) that drives turbine generators to generate electricity is driven by buoyancy resulting from the higher temperature than the surroundings at different heights. In this paper, the maximum chimney height for convection avoiding negative buoyancy at the later chimney and the optimal chimney height for maximum power output are presented and analyzed using a theoretical model validated with the measurements of the only one prototype in Manzanares. The result based on the Manzanares prototype show that as standard lapse rate of atmospheric temperature is used, the maximum power output of 102.2 kW is obtained for the optimal chimney height of 615 m, which is lower than the maximum chimney height with a power output of 92.3 kW. Sensitivity analyses are also performed to examine the influence of various lapse rates of atmospheric temperatures and collector radii on maximum height of chimney. The results show that maximum height gradually increases with the lapse rate increasing and go to infinity at a value of around 0.0098 Km^{-1} and that the maximum height for convection and optimal height for maximum power output increase with large collector radius. In this paper, the maximum chimney height for convection and the optimal chimney height for maximum power output are presented and analyzed based on the Manzanares prototype using a theoretical model validated with the measurements of the only one prototype in Manzanares. With respect to a special collector, negative buoyancy at the latter chimney will occur it chimney height is more than the maximum height. The power plant would obtain the maximum energy conversion efficiency if chimney height is equal to the optimal height. To find out the optimal chimney height for a collector covered at finite ground is significant for the decision-making in determining the dimensions for construction.

5.23 Optimum Wall-To-Wall Spacing in Solar Chimney Shaped Channels in Natural Convection By Numerical Investigation

A numerical study on the laminar and turbulent flows was induced (B.zamora, A.S. Kaiser optimum, 2009) by natural convection in channels, with solar chimney configuration for a wide range of Rayleigh number, several values of the relative wall-to-wall spacing and different heating conditions has been performed. The low-Reynolds k-x turbulence model has been employed to simulate the turbulent cases. Numerical results for the average Nusselt number and the non-dimensional induced mass-flow rate have been obtained for values of Rayleigh number varying from 105 to 1012 for symmetrically, isothermal heating. For this heating condition, a correlation for the thermal optimum aspect ratio has been presented. The sudden change reached in the flow pattern for given conditions drives to obtain a different behavior of the optimum aspect ratio that maximizes the mass-flow rate with respect to the thermal optimum aspect ratio. Depending on the requirements of the real design, the correlations and the results proposed in this work let to optimize the inter-plate spacing that maximize the induced mass flow rate or the heat transfer within the chimney for a given conditions.

5.24 Experimental Study and Simulation of Airflow in Solar Chimney

A detailed mathematical simulation and experimental investigation of airflow in solar chimneys is studied in this paper (Nadia Saifia, Noureddine Settoua, Boubekaur Dokkara, 2012). Several experimental studies were carried out on the solar chimney; their choice depends on the parameter of the design and the thermal performances for different geometrical configurations. The experimental tests show that the field speeds in the chimney is influence by the width of the channel and also of the angle of inclination of the chimney. Therefore, investigations have been carried out to find the effect of inclination on the performance of solar chimney in Ouargla Province, Algeria. The simulation of this problem is implemented into the commercial CFD code Fluent 6.3.26. The conservation equations of mass continuity and energy are solved by the Finite Volume Method. The validation of the results is presented. A good agreement between the experimental results and simulation ones is observed. An experimental and numerical study is undertaken for a titled solar chimney. Experimental study under various chimney slopes (30^0 and 45^0) and air thickness located between absorber and pane (e=10cm, 20cm and 30cm), leads to the following conclusions: the variation in temperature between the absorber and the pane varies according to indent solar flow. Adopted design allows to obtain rather high air flow at chimney outlet, which is interesting to exploit them in natural ventilation Numerical simulation allows determining temperature contours and velocity profile inside solar chimney for various chimney inclination with Rayleigh number Ra=109. By using Boussinesq approximations, main results are summarized that the variation of air blade thickness plays a very important effect to increases significantly air flow. Optimal thermal pulling is reached at chimney inclination angle 45^0.

5.25 Numerical Study on the Thermal Environment of UFAD System with Solar Chimney for the Data Center

To improve the thermal environment in the data center, a solar chimney was integrated (Kai Zhang, Xiaosong Zhang, Shuhong Li, Geng Wang, 2014) with under-floor Air Distribution (UFAD) system in the computational Fluid Dynamics (CFD) software Airpak. By using the validated model, three types of solar chimney, such as solar chimney transversely over the hot and cold aisles, solar chimney lengthways above the cold or hot aisles, were simulated. The comparison between the model calculation result shows that all types of solar chimneys used in this paper has great potential in providing a better temperature and airflow distribution. Especially in the case of the solar chimney above the cold aisle, the temperature in upper zone of cold aisle can be decreased by 130^0C and the temperature field inside the rack is improved greatly without any additional power. Solar chimney is an ideal way to improve the thermal environment of the data center with UFAD system. By using the validated model, three kinds of typical solar chimney were employed separately, which cannot only provide the power to exhaust air but also realize a more reasonable distribution of temperature and airflow in both the room and racks. The comparison between the model calculation result shows that the solar chimney installed above the cold aisle is more effective to this system, in which the temperature in upper zone of cold aisle can be decreased by 13^0 C, and the temperature field inside the rack is improved greatly without any addition power. The application of solar chimney in data center with (UFAD) system can acquire a better cooling effect by the way of improving the distribution of temperature and airflow rather than increasing cooling load, subsequently decreasing the waste of energy and the burden of power system.

5.26 Research for Ventilation Properties of Solar Chimney with Vertical Collector

Theoretical research and numerical simulation for ventilation properties of solar chimney with vertical collector are performed (Zhou Yan, Jing Guang-E, Liu Xiao0hue, Li Qing-Ling, 2011).They are compared with experimental results. Results show that: there are many factors to affect solar chimney ventilation that include heat collection height and weight, solar radiation intensity, inlet and outlet area ratio of chimney and air inlet velocity etc. When the collector height is increased, chimney ventilation is getting higher; but the ventilation increases slowly even decreases; the ventilation increases first and then decreases as growing of the air layer thickness under the same chimney height and width; there exists an optimal ratio between heat collector height and width which makes the ventilation largest; considering the urban architecture image and the influence of the air layer thickness on chimney ventilation, the best air layer thickness is between 0.2m and 0.4m. Besides the airflow temperature in solar chimney increases with chimney height in certain solar radiation intensity. It is consistent with the theoretical analysis and simulation results.

5.27 Solar Ventilation and Heating of Buildings in Sunny Winter Days Using Solar Chimney

The capability of solar chimney lonely to meet the required thermal and ventilation needs of individuals in winter days in investigated (A.P. Haghighi, M.Maerefat, 2014). In the analysis, the heat transfer by natural convection and surface radiation in a 2D vented room in contact with a cold external ambient is studied numerically. The dependence of the system performance on air gap depth of the solar chimney, size of openings, outdoor air temperature and solar radiation have been studied to determine the appropriate operation conditions, regarding thermal comfort criteria. The findings show that the system is capable of providing good indoor air condition at daytime in a room, even with poor solar intensity of 215 W/m^2 and low ambient temperature of 5^0C.

VI. Conclusion

Generation of electricity using solar energy is a feasible alternative for power generation over conventional power plants like thermal and hydraulic power plants. It is an ideal technology that can be adopted in the countries like India that have sunshine almost nine months in the year and lot of free space available for setting large amount of power plants. The only problem is awareness and initiative required and also some sound technical feasibility is required so that this technology can be adopted with ease. In this paper a detail literature review of this technology was performed. The review gives basic principle and operation of this system. It also gives the present status of this technology and various feature scope of this technology. This paper shows that lot of numerical and experimental studies are carried out by keeping Manzanares power plant as reference. It is concluded that such system should be constructed in a very large way to generate large amount of electricity. CFD methods are adopted by many researchers because of high constructional cost of these power plants.

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