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# Solar Chimney Power Plants – Developments and Advancements

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## 1. Introduction

A wide range of existing power technologies can make use of the solar energy reaching Earth. Basically, all those ways can be divided into two basic categories: transformed for use elsewhere or utilized directly – direct – and involving more than one transformation to reach a usable form – indirect. The Solar Chimney Power Plant (SCPP) is part of the solar thermal group of indirect solar conversion technologies.

More specifically, a natural phenomenon concerning the utilization of the thermal solar energy involves the earth surface heating and consequently the adjacent air heating by the sun light. This warm air expands causing an upward buoyancy force promoting the flow of air that composes the earth atmosphere. The amount of energy available due to the upward buoyancy force associated with the planet revolution is so vast that can generate catastrophic tropical cyclones with disastrous consequences.

From another standpoint, such phenomenon can be enhanced and used in benefit of the human well-being. In this way, the SCPP is a device developed with the purpose to take advantage of such buoyancy streams converting them into electricity. For that, a greenhouse – the collector – is used to improve the air heating process, a tall tube – the chimney – promotes the connection between the warm air nearby the surface and the fresh air present in higher atmosphere layers and a system to convert the kinetic energy into electricity – the generator-turbine system (Fig. 1).

## 2. First steps and recent developments

One of the earliest descriptions of a solar chimney power station was written in 1903 by Isidoro Cabanyes, a Spanish artillery colonel. He made public the proposition “Proyecto de motor solar” (solar engine project) introducing an apparatus consisting of an air heater attached to a house with a chimney. In the house interior, a kind of wind propeller was placed with the purpose of electricity production, as shown in Fig. 2, (Cabanyes, 1903).

In 1926 Prof Engineer Bernard Dubos proposed to the French Academy of Sciences the construction of a Solar Aero-Electric Power Plant in North Africa with its solar chimney on the slope of the high height mountain, (Fig. 3., (Günther, 1931)). The author claims that an ascending air speed of 50 m/s can be reached in the chimney, whose enormous amount of energy can be extracted by wind turbines. Fig. 4 shows an solar chimney futurist representation presented by (Günther, 1931). Fig. 5 shows a simple experiment proposed by

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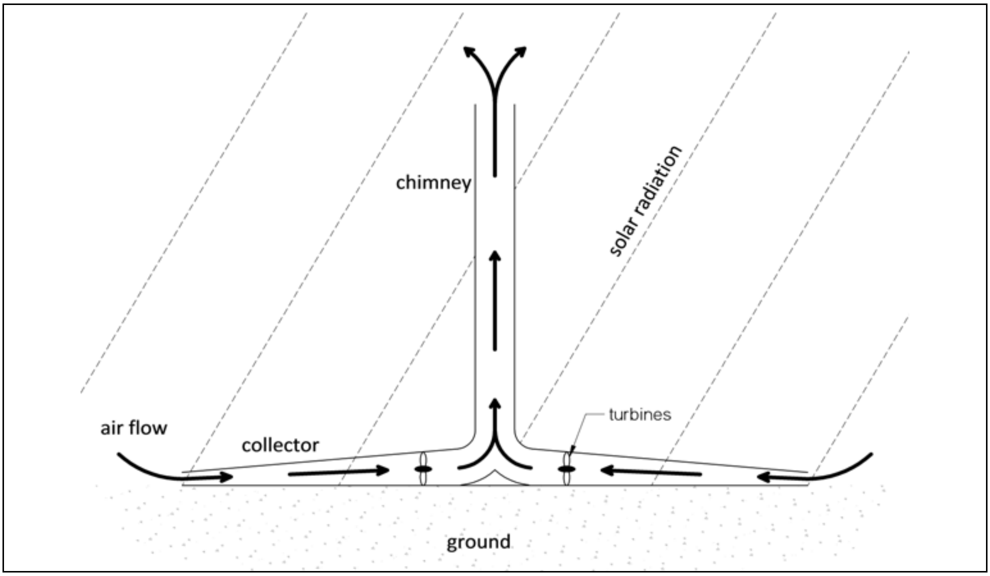


Fig. 1. SCPP components.

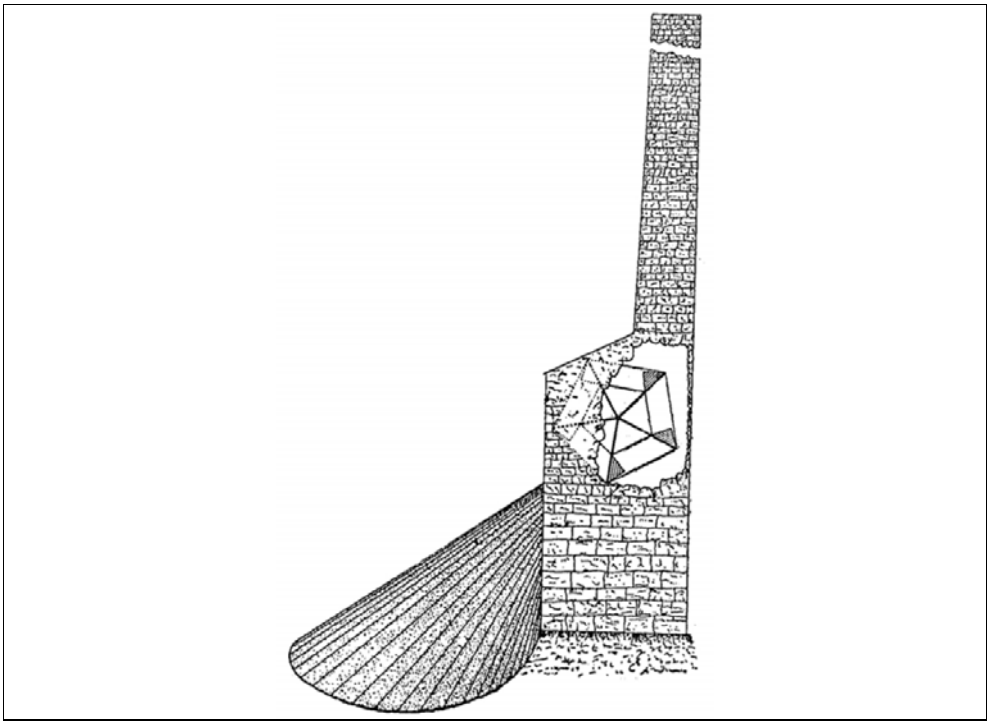

Fig. 2. Solar engine project proposed by Isidoro Cabanyes..

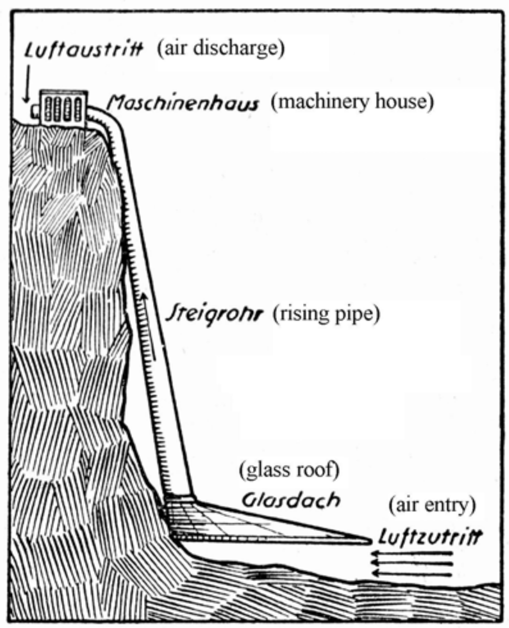


Fig. 3. Solar chimney proposal presented by (Günther, 1931).

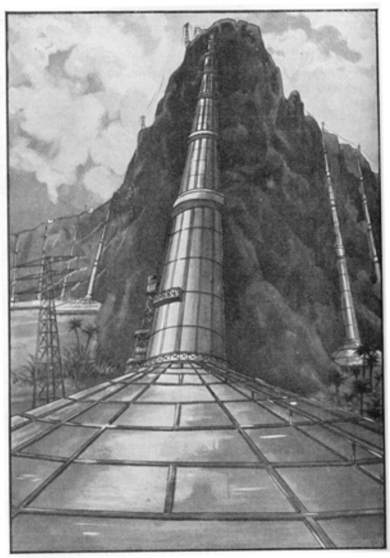

Fig. 4. Solar chimney futurist representation presented by (Günther, 1931).

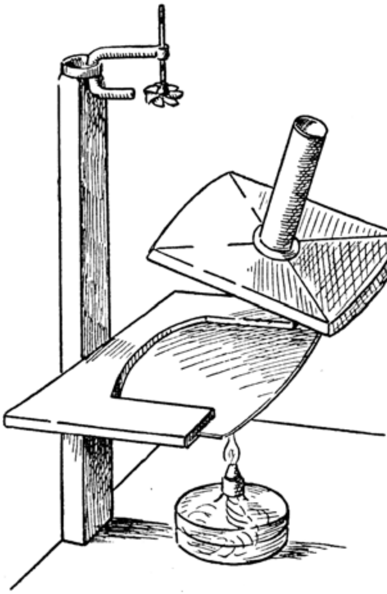

Fig. 5. Solar chimney proposal presented by (Günther, 1931).

Dubos confirming its concept. According to Günther (1931), the plate and the spirit lamp represent the Sahara desert and the solar heat, respectively. The small wind wheel placed on the top represents the wind turbines. If the spirit lamp is positioned under the plate, warm air flows concentrically through the plate reaching the tube. Consequently, the ascendant flow impels the wind wheel.

In the face of the original concepts, the first outstanding action for the SCPP development was the prototype erection in 1982 in Manzanares, Ciudad Real, 150 km south of Madrid, Spain. The chimney height was 195 m and its diameter 10 m. The collector area was 46,000 $m^2$ (about 11 acres, or 244 m diameter). Regardless of its dimensions, this prototype was considered as a small-scale experimental model. As the model was not intended for power generation, the peak power output was about 50 kW. Different glazing materials were tested, as well as, collector sections were used as an actual greenhouse, growing plants under the glass. The construction of the pilot plant were commissioned by the Minister of Research and Technology of the Federal Republic of Germany, (Haaf, *et al.*, 1983). The work was supervised by the energy research project management department of *Kernforschungsanalage (KFA) Jülich GmbH* (the Jülich Nuclear Energy Research Establishment) and fundamental principles of SCPP were found in the form of simple estimates. (Haaf, 1984) divulged preliminary test results including energy balances, collector efficiency values, pressure losses due to friction and losses in the turbine section. (Castillo, 1984) suggested a new "soft" structure approach to the chimney building instead of the conventional "rigid" one.

The SCPP has notable advantages in comparison with other power production technologies, namely - (Schlaich, 1995):

- the collector uses both direct und diffuse radiation;

- the ground provides a natural heat storage;
- the low number of rotating parts ensure its reliability;
- no cooling water is necessary for its operation;
- simple materials and known technologies are used in its construction;
- non OECD countries are able to implement such technology without costly technological efforts

After the prototype operation kick-off, several studies can be found about SCPP. They include transient and steady state fluid dynamic and thermal models, as well as, structural analysis for chimney, collector (including the ground natural heat storage capability) and turbine setups.

### 2.1 SCPP theoretical models

(Mullett, 1987) started the SCPP operational theoretical models development by deriving overall efficiency and relevant performance data. In his calculation, the overall efficiency is proportional the chimney height, returning about 1% for a height of 1000 m. He concluded that the solar chimney is essentially a power generator of large scale. The chimney efficiency is given by the equation (1).

$$\eta_t = \frac{gH}{c_p T_0} \quad (1)$$

Here, $g$ is the gravity [m/s], $H$ is the chimney height [m], $c_p$ is the air heat capacity [J/kg·K] and $T_0$ is the ambient temperature [K]. For instance, with a chimney height of 1000 m and standard conditions for temperature and pressure, the chimney efficiency achieves the maximal value of 3 %. Considering a collector efficiency ($\eta_c$) of 60 % and a turbine efficiency ($\eta_{tur}$) of 80 %, the total system efficiency ($\eta_{tot}$) reaches 1.4%, as shown by equation (2).

$$\eta_{tot} = \eta_t \cdot \eta_c \cdot \eta_{tur} == 0.03 \cdot 0.6 \cdot 0.8 = 0.014 \quad (2)$$

Based on the data from the prototype of Manzanares, (Padki & Sherif, 1989) elaborated extrapolated SCPP models for medium-to-large scale power generation. (Yan, *et al.*, 1991) described a more comprehensive analytical model for SCPP by using practical engineering correlations obtaining equations for air velocity, airflow rate, power output, and the thermo-fluid efficiency and (Padki & Sherif, 1992) also presented a mathematical model for SCPP.

In the end of the 90’s, (Pasumarthi & Sherif, 1998a) built a SCPP small-scale demonstration prototype to study the effect of various geometric parameters on the air temperature, air velocity, and power output of the solar chimney. Further studies conducted by (Pasumarthi & Sherif, 1998b) exploited the collector performance by extending the collector base and by introducing an intermediate absorber. According to them, both enhancements helped to increase the overall chimney power output. In addition, a brief economic assessment of the system costs is presented.

The first known attempt to solve by CFD (Computational Fluid Dynamics) the convective flow in a SCPP is showed by (Bernardes, *et al.*, 1999). He presented a solution for Navier-Stokes and Energy Equations for the natural laminar convection in steady state, predicting its thermo-hydrodynamic behavior. The approach Finite Volumes Method in Generalized

Coordinates was employed allowing a detailed visualization of the effects of geometric of optimal geometric and operational characteristics.
(Kröger & Blaine, 1999) evaluated the influence of prevailing ambient conditions. Their work shows that the air moisture can enhance the driving potential and that under certain conditions condensation may occur. In the meanwhile, (Kröger & Buys, 1999) developed analytical relations for determining the pressure differential due to frictional effects and heat transfer correlations for developing radial flow between the roof and the collector.
A set of differential equations for SCPP is deducted and integrated by (Padki & Sherif, 1999). Expressions for the power generated and the efficiency were obtained by making simplifying assumptions.
(Gannon & von Backström, 2000) introduced a study including chimney friction, system, turbine and exit kinetic energy losses in the analysis. For that, a simple model of the solar collector is used to include the coupling of the mass flow and temperature rise in the solar collector. This work, verified by comparing the simulation of a small-scale plant with experimental data, is useful to predict the performance and operating range of a large-scale plant. A one-dimensional compressible flow approach for the calculation of all the thermodynamic variables as dependent on chimney height, wall friction, additional losses, internal drag and area change was developed by von Backström and Gannon (2000). They concluded that the pressure drop associated with the vertical acceleration of the air is about three times the pressure drop associated with wall friction. For a flared chimney (14%, in order to keep the through-flow Mach number constant virtually), the vertical acceleration pressure drop can be eliminated. (Kröger & Buys, 2001) developed relevant equations for a SCPP.
(Gannon & Von Backström, 2002a) proposed a turbine design based on the design requirements for a full-scale solar chimney power plant integrating the turbine with the chimney. In this way, the chimney base legs are offset radially and act as inlet guide vanes introducing pre-whirl before the rotor reducing the exit kinetic energy. By employing a three-step turbine design method and a free vortex analysis method, the major turbine dimensions are determined. The flow path through the inlet guide vanes and rotor is predicted by a matrix throughflow method. The blade profiles are optimized by using the scheme coupled to a surface vortex method to achieve blades of minimum chord and low drag. The authors stated that the proposed turbine design can extract over 80% of the power available in the flow. Additionally, an experimental investigation of a SCPP design was undertaken by (Gannon & Von Backström, 2002b) and (Gannon & Von Backström, 2003). Results of the experimental model turbine revealed a total-to-total efficiency of 85-90% and total-to-static efficiency of 77-80% over the design range.
(Bernardes, *et al.*, 2003) developed a comprehensive SCPP analysis including analytical and numerical models to describe its performance, i.e., to estimate power output of solar chimneys as well as to examine the effect of various ambient conditions and structural dimensions on the power output. The mathematical model was validated with experimental results and the model was used to predict the performance characteristics of large-scale commercial solar chimneys. It turns out that the height of chimney, the factor of pressure drop at the turbine, the diameter and the optical properties of the collector are important parameters for the SCPP design.
(Schlaich, *et al.*, 2003) describe the functional principle of the Solar Tower and give some results from designing, building and operating a small scale prototype in Mazanares. Future

commercial Solar Tower systems are presented, as well as technical issues and basic economic data.
In his technical brief, (von Backström, 2003) develops calculation methods for the pressure drop in very tall chimneys. Equations for the vertical pressure and density distributions in terms of Mach number allowing density and flow area change with height, wall friction and internal bracing drag are presented. To solve the equations, two simplifications are presented, namely, the adiabatic pressure lapse ratio equation to include flow at small Mach numbers and extension of the hydrostatic relationship between pressure, density, and height to small Mach numbers. Accurate value of the average density in the chimney can be obtained by integration.
(Schlaich, *et al.*, 2004) reintroduces the SCPP concept reinforcing its role as a sustainable option to produce solar electricity at low costs. (Koonsrisuk & Chitsomboon, 2004) analyzed the frictional effect on the flow in a SCPP.
The influence of the atmospheric winds on performance of SCPP was studied by (Serag-Eldin, 2004). By means of a computational model – governing partial differential equations expressing conservation of mass, energy and balance of momentum in addition to a two equation model of turbulence – the flow pattern in the neighborhood of a small-scale SCPP model was computed. The analysis results shown a total degradation of performance with strong winds and significant degradation for low speed winds, except for collector with low inlet height.
(Kirstein, *et al.*, 2005) and (Kirstein & Von Backström, 2006) presented studies concerning the loss coefficient in the transition section between a SCPP turbine and the chimney as dependent on inlet guide vane stagger angle and collector roof height including scaled model experiments and commercial CFD simulations. The very good agreement between the experiments and the simulations permits predictions for a proposed full-scale geometry.
Using the solar chimney prototype in Manzanares as a practical example, (Ming, *et al.*, 2006) carried out numerical studies to explore the geometric modifications on the system performance, showing reasonable agreement with the analytical model. The SCPP performance was evaluated, in which the effects of various parameters on the relative static pressure, driving force, power output and efficiency were investigated.
(Pretorius & Kröger, 2006c) evaluated the performance of a large-scale SCPP. A particular reference plant under specified meteorological conditions at a reference location in South Africa was choose and developed convective heat transfer and momentum equations were employed. The authors claim that 24 hr plant power production is possible and that plant power production is a function of the collector roof shape and inlet height. Furthermore, more accurate turbine inlet loss coefficient, quality collector roof glass and various types of soil on the performance of a large scale SCPP are introduced ((Pretorius & Kröger, 2006b)). Results pointed out that the heat transfer correlations employed reduced the plant power output significantly. A more accurate turbine inlet loss coefficient has no noteworthy effect, at the same time as utilizing better quality glass enhances plant power production. Simulations employing Limestone and Sandstone soil gave virtually similar results to a Granite-based model.
(Von Backström & Fluri, 2006) investigated analytically the validity and applicability of the assumption that, for maximum fluid power, the optimum ratio of turbine pressure drop to pressure potential (available system pressure difference) is 2/3. They concluded that the constant pressure potential assumption may lead to overestimating the size of the flow

passages in the plant, and designing a turbine with inadequate stall margin and excessive runaway speed margin.

The effects of the solar radiation on the flow of the SCPP were analyzed by (Huang, *et al.*, 2007). Boussinesq approximation and Discrete Ordinate radiation model (DO) were introduced in the model and simulations were carried out.

(Koonsrisuk & Chitsomboon, 2007) proposed the use of dimensionless variables to conduct the experimental study of flow in a small-scale SCPP for generating electricity. The similarity of the proposed dimensionless variables was confirmed by computational fluid dynamics.

(Ming, *et al.*, 2007) set up different mathematical models for heat transfer and flow for the collector, chimney and turbine. After the validation with the Manzanares prototype, they suggested that the output power of MW-graded can exceed 10 MW.

A new mathematical model based on the concept of relative static pressure was developed by (Peng, *et al.*, 2007). According to them, optimized local geometric dimensions between the collector outlet and the chimney inlet, the local velocity at this place ca increase 14% the SCPP performance, temperature profiles are more uniform, and the relative static pressure decreases about 50% improving the system energy conversion and reducing the energy losses.

(Pretorius & Kröger, 2007) presented a sensitivity analysis on the influence of the quality, thickness, reflectance, emissivity, shape, and insulation of the collector roof glass, the cross section of the collector roof supports, various ground types, ground surface roughness, absorptivity and emissivity, turbine and bracing wheel loss coefficients, and the ambient pressure and lapse rate on the performance of a large-scale (reference) solar chimney power plant. Computer simulation results point out that collector roof insulation, emissivity and reflectance, the ambient lapse rate, and ground absorptivity and emissivity all have a key effect on the power production of such a plant.

(Ming, *et al.*, 2008a) continued their work carrying out numerical simulations analyzing characteristics of heat transfer and air flow in the solar chimney power plant system with an energy storage layer including the solar radiation and the heat storage on the ground. They concluded that the ground heat storage depends on the solar radiation incidence. Higher temperature gradients also increase the energy loss from the ground ((Ming, *et al.*, 2008b)) and (Ming, *et al.*, 2008c)). Subsequently, (Tingzhen, *et al.*, 2008) included a 3-blade turbine in the model simulation and validated the model, turning out power out and turbine efficiency of 10 MW and 50%, respectively.

Due to the use of different heat transfer coefficients found in the literature, namely those of ((Bernardes, 2004b),(Pretorius & Kröger, 2006a)), (Bernardes, *et al.*, 2009) made a comparison of the methods used to calculate the heat fluxes in the collector and their effects on solar chimney performance. Notwithstanding the difference between the heat transfer coefficients, both approaches returned similar air temperature rises in the collector and therefore, comparable produced power.

(Koonsrisuk & Chitsomboon, 2009) went on with their previous study, namely (Koonsrisuk & Chitsomboon, 2007), trying to maintain dynamic similarity between the prototype and its theoretical model keeping the same solar heat flux. They showed that, for the same heat flux condition, all dimensional parameter, except the roof radius, must remain similar. They also revealed some engineering interpretations for the similarity variables.

SCPP energy and exergy balances were carried out by (Petela, 2009), turning out the energy distribution in the components for a input of 36.81 MW energy of solar radiation (or an equivalent input of 32.41 MW of radiation exergy), including also a sensibility analysis.

More recently (Bernardes and von Backström, 2010) performed a study regarding the performance of two schemes of power output control applicable to solar chimney power plants. It was revealed that the optimum ratio is not constant during the whole day and it is dependent of the heat transfer coefficients applied to the collector.

## 3. SCPP analysis for specific sites

(Dai, et al., 2003) analyzed a solar chimney power plant to provide electric power for remote villages in northwestern China. Three counties in Ning Xia Hui Autonomous region, namely, Yinchuan, Pingluo, and Helan with good solar radiation availability were selected as sites to simulate a SCPP model. In according to the authors, a SCPP consisting of a 200 m height and 10 m diameter chimney, and the 500 m diameter solar collector can produce 110 ~ 190 kW electric power on a monthly average all year.

(Bilgen and Rheault, 2005) developed a mathematical model based on monthly average meteorological data and thermodynamic cycle to simulate the SCPP power production at high latitudes. Three locations in Canada, namely Ottawa, Winnipeg and Edmonton were choose to evaluate a 5 MW nominal power production plant. The authors also suggested the construction of a sloped collector field at suitable mountain hills in order to work as a collector. Next, for this proposition, a short vertical chimney is added to install the vertical axis air turbine. They also shown that such plant can produce as much as 85% of the same plants in southern locations with horizontal collector field and the overall thermal performance of these plants is a little less than 0.5%.

SCPP for rural villages was studied by (Onyango and Ochieng, 2006) emphasizing some features for power generating. They disclosed that for a temperature ratio = 2.9 (i.e., the difference between the collector surface temperature and the temperature at the turbine to the difference between the air mass temperature under the roof and the collector surface temperature) an 1000 W of electric power can be generated. The minimum dimension of a practical by a reliable SCPP to assist approximately fifty households in a typical rural setting has been determined to be chimney length = 150 m, height above the collector = chimney radius = 1.5 m.

(Zhou, et al., 2007b) developed mathematical model to investigate power generating performance of a SCPP prototype. The steady state simulation returned power outputs for different global solar radiation intensity, collector area and chimney height. The simulation results were validated with the measurements.

## 4. SCPP turbine developments

(Gannon & Von Backström, 2003), (Gannon & Von Backström, 2002b) and (Gannon & Von Backström, 2002b) were the first to develop an experimental investigation of the performance of a solar chimney turbine. The design consisted of a single rotor by using inlet guide vanes to introduce pre-whirl. Such strategy reduces the turbine exit kinetic energy at the diffuser inlet and assists the flow turning in the IGV-to-rotor duct. Total-to-total efficiencies of 85-90% and total-to-static of 77-80% over the design range were measured.

(Von Backström & Gannon, 2004) presented analytical equations in terms of turbine flow and load coefficient and degree of reaction, to express the influence of each coefficient on turbine efficiency. Analytical solutions for optimum degree of reaction, maximum turbine efficiency for required power and maximum efficiency for constrained turbine size were

found. According to the authors, a peak turbine total-to-total efficiency of around 90% is achievable, but not necessarily over the full range of plant operating points.
Some structural aspects of classical wind energy turbines, like their high-cycle dynamic loading and reaction as well as their fatigue behavior were exposed by (Harte & Van Zijl, 2007). Structural challenges concerning wind action, eigenfrequencies, stiffening and shape optimization with special focus on the inlet guide vanes were discussed for SCPP's.
(Fluri & von Backström, 2008) analyzed many different layouts for the SCPP turbogenerator. Turbine layouts with single rotor and counter rotating turbines, both with or without inlet guide vanes were considered. They concluded that the single rotor layout without guide vanes performs very poorly; the efficiency of the other three layouts is much better and lies in a narrow band.
(Tingzhen, et al., 2008) performed numerical simulations on SCPP's coupled with turbine. The model was validated with the measurements from the Spanish prototype, obtaining a maximum power output higher than 50 kW. Subsequently, the authors presented the design and the simulation of a MW-graded solar chimney power plant system with a 5-blade turbine. The numerical simulation results show that the power output and turbine efficiency are 10 MW and 50%, respectively, which presents a reference to the design of large-scale SCPP's.

## 5. SCPP experimental analysis

(Pasumarthi & Sherif, 1998a; b): The solar chimney is a natural draft device which uses solar radiation to provide upward momentum to the in-flowing air, thereby converting the thermal energy into kinetic energy. A study was undertaken to evaluate the performance characteristics of solar chimneys both theoretically and experimentally. In this paper, a mathematical model which was developed to study the effect of various parameters on the air temperature, air velocity, and power output of the solar chimney, is presented. Tests were conducted on a demonstration model which was designed and built for that purpose. The mathematical model presented here, was verified against experimental test results and the overall results were encouraging. his paper describes details of the experimental program conducted to assess the viability of the solar chimney concept. A demonstration model was designed and built and its theoretical and experimental performance was examined. Two experimental modifications were tried on the collector: (1) extending the collector base and (2) introducing an intermediate absorber. The former modification helped in enhancing the air temperature, while the latter contributed to increasing the air temperature as well as the mass flow rate inside the chimney. Both enhancements helped to increase the overall chimney power output. Theoretical and experimental performance results of this demonstration model are presented in this paper, while the mathematical model developed in Part I was used to predict the performance of much larger systems. Mathematical model results were validated by comparing them to published data on the solar chimney system built in Manzanares, Spain. Also, an economic assessment of the system costs are presented.
(Gannon & Von Backström, 2002b): An experimental investigation of a solar chimney turbine design is undertaken. The aim of the program is to demonstrate and evaluate a proposed solar chimney turbine design. The measured results of an experimental model turbine are presented and the turbine efficiency calculated. The current turbine design has a total-to-total efficiency of 85-90% and total-to-static efficiency of 77-80% over the design

range. Secondary objectives are to compare the measured and predicted results and through investigation of the experimental results suggest improvements to the turbine design.
(Zhou, *et al.*, 2007a): A pilot experimental solar chimney power setup consisted of an air collector 10 m in diameter and an 8 m tall chimney has been built. The temperature distribution in the solar chimney power setup was measured. Temperature difference between the collector outlet and the ambient usually can reach 24.1 Â°C, which generates the driving force of airflow in the setup. This is the greenhouse effect produced in the solar collector. It is found that air temperature inversion appears in the latter chimney after sunrise both on a cool day and on a warm day. Air temperature inversion is formed by the increase of solar radiation from the minimum and clears up some time later when the absorber bed is heated to an enough high temperature to make airflow break through the temperature inversion layer and flow through the chimney outlet.
(Ferreira, *et al.*, 2008): Solar dryers use free and renewable energy sources, reduce drying losses (as compared to sun drying) and show lower operational costs than the artificial drying, thus presenting an interesting alternative to conventional dryers. This work proposes to study the feasibility of a solar chimney to dry agricultural products. To assess the technical feasibility of this drying device, a prototype solar chimney, in which the air velocity, temperature and humidity parameters were monitored as a function of the solar incident radiation, was built. Drying tests of food, based on theoretical and experimental studies, assure the technical feasibility of solar chimneys used as solar dryers for agricultural products. The constructed chimney generates a hot airflow with a yearly average rise in temperature (compared to the ambient air temperature) of 13 ± 1 °C. In the prototype, the yearly average mass flow was found to be 1.40 ± 0.08 kg/s, which allowed a drying capacity of approximately 440 kg.
(Ming, *et al.*, 2008c): A small scale solar chimney system model has been set up, and the temperature distribution of the system with time and space, together with the velocity variation inside the chimney with time, has been measured. The experimental results show that the temperature distributions inside the collector and the effects of seasons on the heat transfer and flow characteristic of system show great agreement with the analysis, while the temperature decrease significantly inside the chimney as the chimney is very thin which causes very high heat loss.

## 6. SCPP structural analysis

(Harte & Van Zijl, 2007) presented some structural aspects of classical wind energy turbines, like their high-cycle dynamic loading and reaction as well as their fatigue behaviour. Actual research results concerning pre-stressed concrete tower constructions for wind turbines will be focused on. For the solar chimney concept the structural challenges concerning wind action, eigenfrequencies, stiffening and shape optimization with special focus on the inlet guide vanes will be discussed.

## 7. SCPP ecological analysis

(Bernardes, 2004a) performed is a comprehensive evaluation of impacts caused by mass and energy flows of solar chimneys systems from its design through to production and then final disposal using the method of Life Cycle Assessment. The conventional Life Cycle Assessment method was improved by an additional sectoral analysis (input-output analysis), namely Hybrid Approach. The study was an important contribution for the integration of Life Cycle Assessment in the decision making process in the renewable energy sector and for an integrated evaluation of processes.

## 8. SCPP economical analysis

In their first approach (Haaf, *et al.*, 1983) concluded, from the relationships between the physical principles on the one hand and the scale and construction costs on the other, that economical power generation will be possible with large-scale plants designed for up to 400 MW/pk

(Pretorius & Kröger, 2008) undertook a study to stablish a thermoeconomically optimal plant configurations for a large-scale SCPP. For that, an approximated cost model was developed, giving the capacity for finding optimum plant dimensions for different cost structures. Thermoeconomically optimal plant configuration were obtained through multiple computer simulations and results comparison to the approximated cost of each specific plant.

A study developed by (Fluri, *et al.*, 2009) revealed that previous economical models may have underestimated the initial cost and levelised electricity cost of a large-scale solar chimney power plant. It also showed that carbon credits significantly can reduce the levelised electricity cost for such a plant.

## 9. Alternative concepts and applications

Probably (Ferreira, *et al.*, 2008) were the first to propose a solar chimney as a device to dry agricultural products. A small scale prototype solar chimney was built, in which the air velocity, temperature and humidity parameters were monitored as a function of the solar incident radiation. Based on theoretical and experimental studies Drying tests reveled the technical feasibility of solar chimneys used as solar dryers for agricultural products. A hot airflow with a yearly average rise in temperature (compared to the ambient air temperature) of 13 ± 1 °C could be achieved allowing a drying capacity of approximately 440 kg.

(Zhu, *et al.*, 2008) proposed different heat storage styles for SCPP. The experimental studies showed that the temperature difference in the sealed water system is the largest, while the open water system has the lowest one because of the latent heat consumed by water evaporation. The study also showed that there is the temperature distribution optimization of the system if the heat loss part of the collector to be avoided.

The concept for producing energy by integrating a solar collector with a mountain hollow is presented and described by (Zhou, *et al.*, 2009). As in a conventional SCPP, the hot air is forced by the pressure difference between it and the ambient air to move along the tilted segment and up the vertical segment of the 'chimney', driving the turbine generators to generate electricity. The author claimed that such concept provides safety and reduces a great amount of construction materials in the conventional chimney structure and the energy cost to a level less than that of a clean coal power plant.

The hypothesis of combining a salinity gradient solar pond with a chimney to produce power in salt affected areas is examined by (Akbarzadeh, *et al.*, 2009). The salinity in northern Victoria, Australia was analyzed and salinity mitigation schemes were presented. It was shown that a solar pond can be combined with a chimney integrating an air turbine for the production of power. A prototype of a solar pond of area 6 hectares and depth 3 m with a 200 m tall chimney of 10 m diameter was investigated and

## 10. Conclusion

The previous literature review about SCPP presents an outstanding technological development enlightening considerable advances in its construction, operation, including its technical economical and ecological relevant facets.

In contrast with other solar facilities, SCPPs can be used above and beyond power production. Very relevant byproducts are distilled water extracted from ocean water or ground water. Under certain conditions, agribusiness may be appropriate under the solar collector. It can involve fruits and vegetables, medicinal and aromatic essential oils from herbs and flowers, seaweeds and planktons, blue-green algae, ethanol and methane, biodiesel and all manner of vegetable and plant derivatives, etc. Besides, remaining biomass is useful creating additional heat during composting.

The insertion of SCPP in the power generation market requires scalability and base, shoulder and peak load electricity generation. Further developments should meet such localized requirements.

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The present “Solar Energy” science book hopefully opens a series of other first-hand texts in new technologies with practical impact and subsequent interest. They might include the ecological combustion of fossil fuels, space technology in the benefit of local and remote communities, new trends in the development of secure Internet Communications on an interplanetary scale, new breakthroughs in the propulsion technology and others. The editors will be pleased to see that the present book is open to debate and they will wait for the readers’ reaction with great interest. Critics and proposals will be equally welcomed.