Towers of power - the solar updraft tower

by CM Meyer, technical journalist

Mention the words "La Mancha", and many people would associate them with the famous eccentric Spanish character "Don Quixote of La Mancha", from the novel of the same name by Miguel de Cervantes. For did not Cervantes place his famous character in the dusty, windswept plain of La Mancha, in central Spain many, many years ago? And did not Don Quixote once try and attack some windmills in La Mancha, believing them to be ferocious giants?

In May, 1982 Spaniards living near the small central town of Manzanares, 150 km South of Madrid, saw a strange giant arising. It was a metal tower nearly 200 m high made of sheet steel rings, surrounded by an array of plastic sheeting 240 m across (see Fig. 1). Some doubtless thought that a crazy descendant of Don Quixote was at work. For Manzanares was situated in the windswept plateau of La Mancha, not too far from the windmills which Don Quixote had attacked in the early 1600s.

Contrary to what many thought, there was a serious purpose in what was being built. The strange giant tower being pushed slowly skywards was the first prototype of a solar updraft tower, better known as a solar chimney. And it was being built to test the giant ideas of one man, Jörg Schlaich, who had envisioned solar towers taller than a kilometer being built in remote, sun-baked areas to generate electricity.

Towers 1 000 m high are a challenge, but they can be built today" Jörg Schlaich et al. (Ref.10;226).

What is the solar chimney? Is it, like Don Quixote's dreams of knightly deeds, something impractical that natural forces will sooner or later bring crashing down?

Or, in years to come, will solar chimneys prove to be very practical ways of generating electricity: especially in dry, underdeveloped areas? Maybe these slender towers, taller than one km and surrounded by a round shiny sea of glass or plastic, will eventually dot the world's deserts and drive development there. Only time will tell. To see what the solar chimney is, and is not, and what it might achieve, one must first understand something of Jörg Schlaich's vision. And see why what happened at Manzanares, after the giant tower was commissioned on 7 June 1982, changed solar chimneys from science fiction into scientific facts.

One man's giant vision

"I was in Khartoum recently, where work was not possible since they had no electricity," Jörg Schlaich *says, "but at the same time, just outside the city, they have a desert in which the insolation [energy from sunlight] is fantastic. They could really make use of it".* (Ref.7;30).

Anyone travelling in an aircraft will sooner or later experience the power of up or downdrafts of air. You may be a passenger in a jet aircraft, where sudden turbulence makes you violently airsick. Better, you could be piloting a glider, and feel at first hand how powerful updrafts of air can carry you effortlessly skywards; sometimes even far above the cruising altitudes of most jet airliners. Or, worse, the airliner you are travelling in could be tossed violently up or down in apparently calm, windless air. This third example is by far the most dangerous situation to be in, as the clear air turbulence (CAT for short) that causes it is still not properly understood, and has been responsible for fatal aircraft accidents.

But the focus here is not aircraft, but hot air; specifically, the energy in air heated by the sun. And, over the centuries, people have come up with various ways to use this energy; particularly, using various forms of chimney. Long before 1600, the famous Italian genius Leonardo da Vinci had designed a chicken barbecue with a windmill driven by the hot upwind in the chimney.

In the 1970s, Jörg Schlaich, one of the world's most innovative civil engineers, was trying to solve an old problem, that of removing the heat from water used to cool a nuclear power plant, by a completely new approach; using proposed 800 m cooling towers.

Schlaich's solution was something radically new. He ended up by removing the nuclear power plant, and replacing it with a very different source of heat, a huge, circular sunlight collector. His solar chimney was, in essence, a huge, circular glass greenhouse sealed tightly around a very tall tower in its centre. Open at the sides, air was heated beneath the glass by the sun (using the greenhouse effect) as it sped towards its only possible escape route: a tall, slender cooling tower in the center.

Before it could rise up the cooling tower, cool, and escape to the atmosphere, the heated air was used to do useful work. At the bottom of the tower, where it joined the solar collector, was a huge turbine. The heated air had to pass through the turbine,

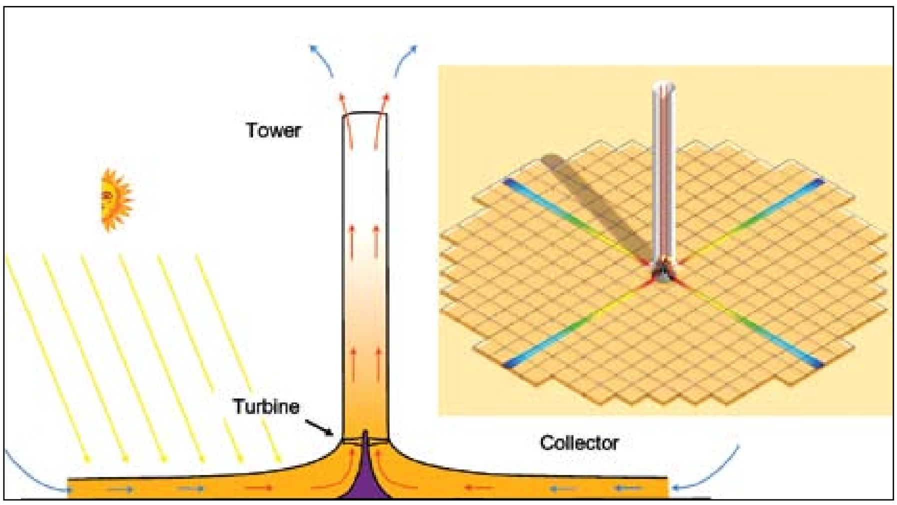

Fig. 1: The solar updraft tower built at Manzanares, Spain, in 1982 (Sclaich Bergermann Solar, Stuttgart).

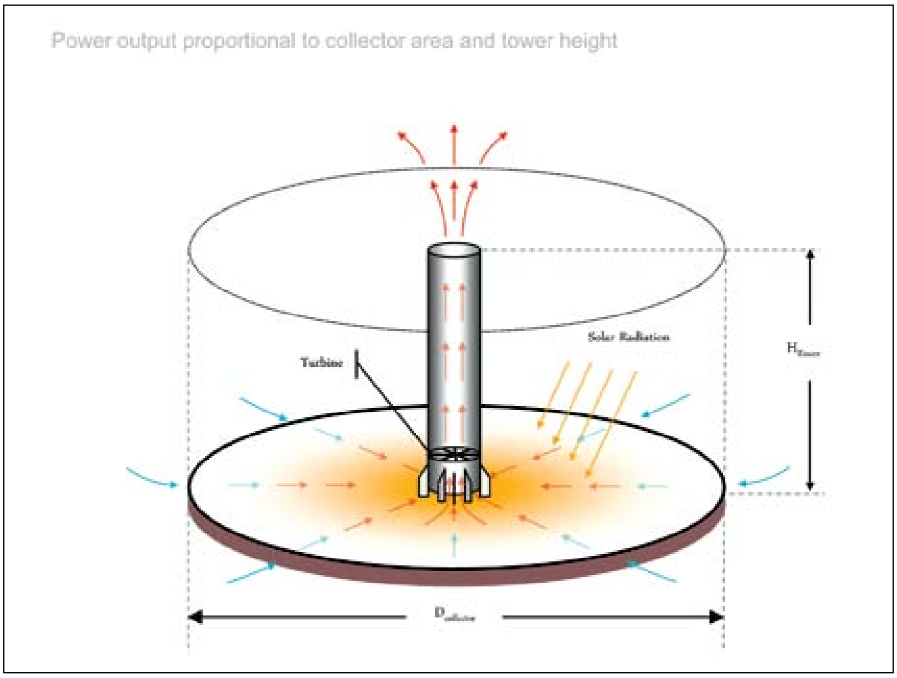

Fig. 2: Principle of the solar updraft tower (Schlaich Bergermann Solar, Stuttgart).

spin its blades and generate electricity before it could rise, cool and escape. The whole concept was something like a hydropower generator, where water in a dam is being forced to flow through a turbine, but with everything inverted. That is, instead of water forced down by gravity to flow over a turbine to generate electricity, hot air is forced up through a turbine because air pressure at the bottom of the cooling tower (the hot end) is higher than at the top of the cooling tower (the cooler end). The entire principle is summarised in Fig. 2.

Ironically, as the idea came from cooling a nuclear power plant, some say solar towers will eventually help replace nuclear power plants. But Schlaich's idea still had to be demonstrated before it could be considered as anything more than science fiction. Even though, as we shall see, the principles of the solar chimney had already been known for centuries.

From vision to prototype

"The solar updraft tower meets…conditions [for the wide use of renewable energy]. Its three essential elements – solar air collector, chimney/tower, and wind turbine – have been familiar for centuries. Their combination to generate electricity has already been described in 1931" Jörg Schlaich et al. (Ref.10;225.)

One of the first known designs for a possible solar chimney power plant to generate electricity was described well before 1931, in 1903. A Spaniard, Colonel Isidoro Cabanyes proposed a design in the 25 August 1903 issue of "La Energia Eléctrica", entitled "Projecto de motor solar". In this bizarre contraption, a collector resembling a large skirt heats air, and carries it upwards towards a pentagonal fan inside a rectangular brick structure vaguely resembling a fireplace (without a fire). The heated air makes the fan spin and generate electricity, before it escapes up a 63,87 m tall chimney, cools, and joins the atmosphere. Exactly why the chimney should be 63,87 m high is not very clear.

Simpler solar chimneys have been used for ventilation for centuries, particularly in the Middle East, as well as by the Romans. In its simplest form, the solar chimney is a chimney painted black to absorb the sun's heat. This creates an updraft of air, and can be used to ventilate and cool the building below. But it was Schlaich's vision, together with a sincere desire to produce a practical means for the world's poorer countries to utilise renewable energy, that led to the solar chimney (more technically, a solar updraft tower) as we know it today. It was his drive and determination that obtained funding from the German government to build a prototype at Manzanares in1982.

What many lose sight of is that the prototype he supervised was just that: a prototype. It was intended to test materials, methods and techniques, not produce an economically viable tower. Schlaich proved his principle worked, but also exposed its limitations. While some findings are quite well known and are discussed in more detail in the next article, let us first focus on some less obvious results from the Manzanares trial. For, as we shall very soon see, the issues raised go to the heart of arguments about the solar chimney.

A question of efficiency

"The highest power output during this period, 41 kW, was measured at an irradiation level of approx 1040 W/m²" (Ref.13;142-145.)

By doing a simple calculation, one can estimate the total solar energy that reached the solar chimney prototype at Manzanares when it was producing its highest output between July and September 1982, and then calculate its efficiency for that period. Bearing in mind that the collector for the solar chimney was not a perfect circle, an average radius for it can still be estimated with reasonable accuracy as 122 m. Squaring this figure and multiplying it by π gives the area (just over 46 759 m²), and multiplying this figure by the irradiation level of approximately 1040 W/m², gives a total estimate of 48 629 kW.

In other words, 48 629 kW of solar energy striking the Manzanares solar chimney prototype produced 41 kW of electrical energy output, an efficiency of something like 0,08%. This efficiency rises to around 0,11% if later published figures are used (for 8 June 1987, when the tower later managed to produce closer to 50 kW of electrical energy output when the insolation (solar energy irradiation level) was just over 1000 W/m², and the collector area was given as 45 000 m².

By comparison, practical photovoltaic installations can have an efficiency of around 12 - 14%, while solar towers using molten salt can achieve an efficiency of around 15%. All which shows an uncomfortable truth about solar towers of this type; they are horribly inefficient at converting sunlight into electricity. In fact, this is also the biggest problem for solar chimneys, as the most economical way to increase their efficiency is to make them taller - much, much taller. And building concrete towers a km or more in height is far from straightforward.

Especially when one remembers that budgets for solar chimneys often assume a working life of eighty or more years. In other words, for a solar chimney to be economical, it must withstand freak weather conditions that might occur only once a century. And all its parts, be they concrete, metal, glass or plastic, should, ideally, also last for eighty or more years.

Especially important are the metal spokes vaguely resembling huge bicycle wheels. These are to be built into the chimney at

Fig. 3: The prototype solar chimney.

various heights to damp a whole range of complex vibrations that could otherwise destroy the tower when sudden gusts or storms buffet it. These spokes will have to withstand corrosion for more than a century, and even stainless steel may not prove tough enough, perhaps titanium or even platinum might be needed.

Designing a dam to withstand a flood estimated to occur once in 100, 200 or even 500 years can be done. But how does one characterise the winds that might occur once in 100, 200 or even 500 years? This is far from easy, especially as the global climate is changing, and tables of maximum wind velocities for the past century may prove of little use in estimating the perfect storms to come. And without this knowledge, can a solar chimney of a kilometer or higher be safely built?

A very complex problem

"The fathers of the solar chimney concept gave little attention to the scale of the structure they wanted to build. In their minds it was a fairly simple matter: construct an upright cylinder 1 500 m tall in a desert. But to a structural engineer such a request is not as simple as it seems" (Ref.18;12).

One of the main problems of the solar chimney is trying to predict what will happen to it during thunderstorm associated winds or gusting. Put another way, a major threat to the structural integrity of the solar chimney power plant structure is wind-induced resonance, or aerodynamic instability. This is arguably the biggest and most complex problem facing those who want to build a solar chimney taller than a kilometer. For it is at roughly one km altitude that the effect of ground friction [on wind] dies out, and another type of wind, geostrophic, becomes more dominant in wind patterns.

In other words, wind blowing with a different velocity, and perhaps even a different direction, could be expected at altitudes of roughly one km, causing different stresses in different areas of the structure.

A slender structure need not be a km high to be damaged by wind. What was the world's tallest structure, the Warsaw Radio mast, 646,38 m tall, was damaged by wind-induced oscillations at the mast, the backstage insulators and the [supporting] guys before an error in maintenance finally caused it to collapse on 8 August 1991.

Even a low-speed wind can sometimes cause catastrophic damage, as the designers of the Tacoma Narrows bridge discovered on 7 November 1940, when the structure collapsed. The wind that caused the central span to vibrate slowly about its center line (called twisting mode resonance), was only 67 km per hour, but it blew for a long time, and caused more energy from the wind to be absorbed than the bridge could dissipate. Finally, at 11:00 on 7 November 1940, the central span collapsed into the sea below.

The original Manzanares solar chimney prototype itself also collapsed, but in a storm eight years after being built. This was, however, not unexpected, as the structure was not expected to last longer than the intended test period of three years and was designed for easy dismantling after the test instead of permanence. Consequently, the chimney guy rods were not protected against corrosion, and after eight years, they had rusted through, finally breaking in a storm. But, if a solar chimney is to stand for eighty years or even longer and one estimate is 160 years, then it cannot have metal parts, especially any metal parts carrying a load, rusting through after a mere eight years.

A further problem confronting a 1,5 km high solar chimney proposed for the northern Cape near somewhere near Upington is that wind direction inversions are a frequent phenomenon, resulting from temperature inversions. This makes characterising the complex range of oscillations that winds could cause to such a very tall structure even more complex. And damping each and every possible oscillation before it can shake such a tower to pieces becomes a very complicated job. And knowing exactly what oscillations can be caused by a whole range of wind speeds is extremely important if this type of structure is to stay standing. As the collapse of the Tacoma Narrows bridge showed, sometimes even an obscure resonance, there at 0,2 Hz, can cause dangerous oscillations from wind.

But perhaps there is an answer to all this, summarised by a single word: overdesign. Brooklyn Bridge, built to connect Manhattan and Brooklyn in New York City, was opened on 24 May 1883. It is still standing today and, according to a recent Scientific American article, should continue to stand for several centuries to come.

Its secret? The designer, John Roebling, designed a bridge and truss system that was six times as strong as he thought it needed to be. When the cabling used to support the huge bridge was found to use inferior quality wire, a calculation found the bridge was four rather than six times as strong as necessary. For safety, 250 cables were added. Today, Brooklyn Bridge is a living monument to John August Roebling. Actually, it is a monument to the Roebling family, for John died of a tetanus infection to a foot injury during surveying operations. His son, Washington, who took over the job, nearly died from decompression sickness while building the towers upon which the bridge rests. It was his wife, Emily, who became his aide, and ensured that Washington's instructions for completing the bridge were communicated to the builders.

Which all goes to show: if a civil engineer is confident that something can be built, eventually it will be built. However, what if the person concerned is not a civil engineer but an ex stockbroker? The strange but true story of attempts by a futures trader to build the world's tallest tower of power in Australia follows in the next article. ❖