

(12) **UK Patent Application** (19) **GB** (11) **2 404 433** (13) **A**

(43) Date of A Publication **02.02.2005**

(21) Application No: **0317706.0**  
(22) Date of Filing: **29.07.2003**

(71) Applicant(s):  
**Robin Matthew Hilder**  
**16 Croydon Street, SHEFFIELD, S11 8BD,**  
**United Kingdom**

(72) Inventor(s):  
**Robin Matthew Hilder**

(74) Agent and/or Address for Service:  
**Robin Matthew Hilder**  
**16 Croydon Street, SHEFFIELD, S11 8BD,**  
**United Kingdom**

(51) INT CL<sup>7</sup>:  
**F24J 2/07, E04H 12/28 12/34, F23J 11/00 13/00, F23L**  
**17/02, F24J 2/50**

(52) UK CL (Edition X):  
**F4J J2B J2H J2J J2L J2X**  
**F4U U6250**

(56) Documents Cited:  
**DE 029622549 U** **JP 2003056211 A**

(58) Field of Search:  
UK CL (Edition V) **F4J, F4U**  
INT CL<sup>7</sup> **E04H, F23J, F23L, F24J**  
Other: **ONLINE DATABASES: WPI EPODOC JAPIO**

(54) Abstract Title: **Balloon supported flexible chimney especially for use in solar power stations**

(57) A lightweight flexible chimney supported by a tethered balloon (8) for use as an alternative to a free standing chimney in a solar thermal power station. The invention allows for the use of larger pressure differentials between the interior and exterior of the thin membrane walled tube (6) by applying tension to sections of the membrane via a series of longitudinally spaced apart support features (12, 13) attached to the membrane and a flexible tensioned member (7) held taught between the balloon and the base of the chimney. The solar power station comprises a glazed circular green house structure (1), open around its circumference, with at least one air turbine (5) below the chimney.

FIG 2

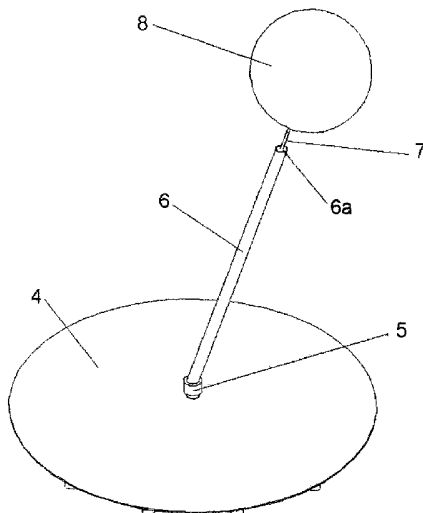
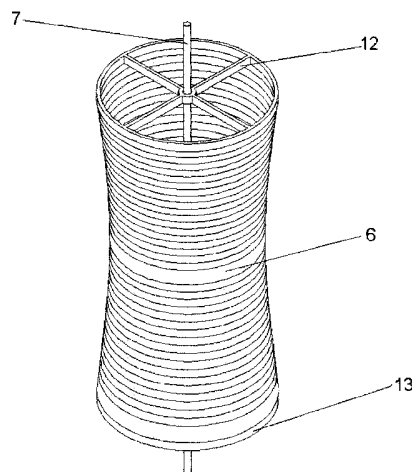
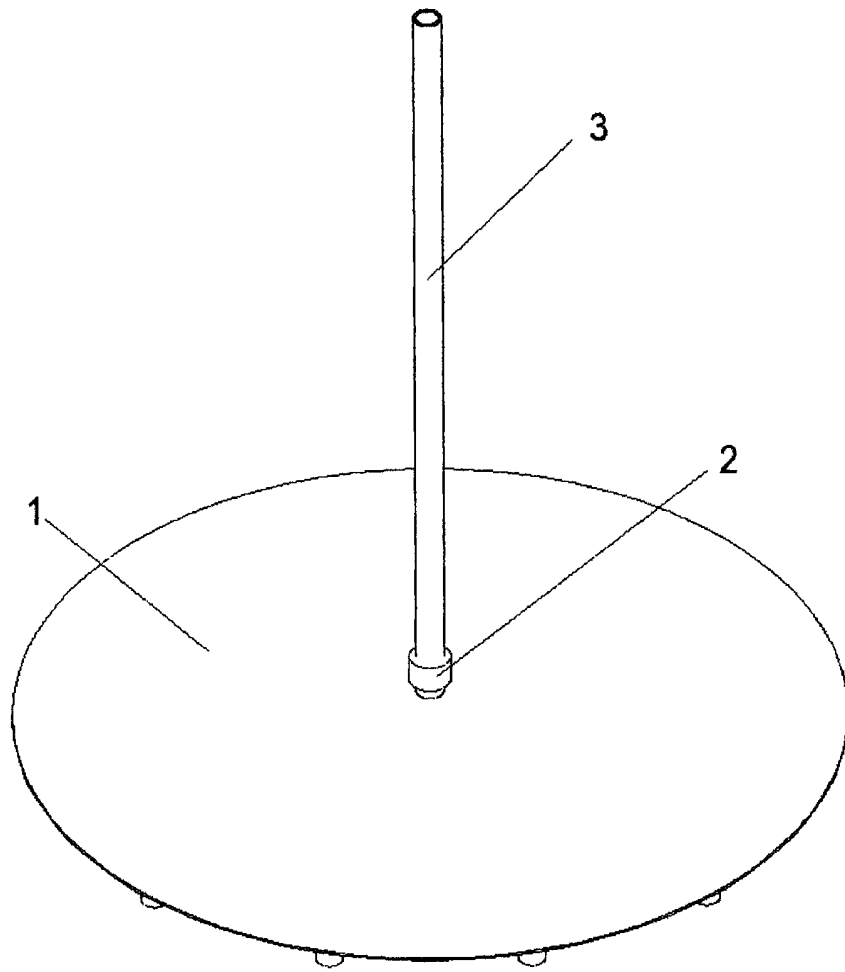


FIG 1



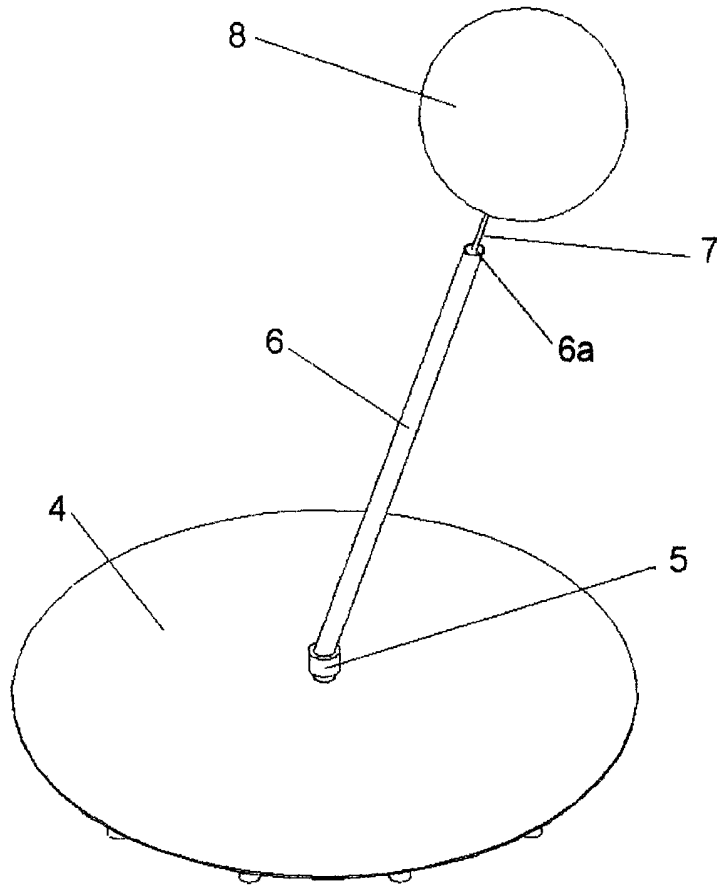
1/10

FIG 1



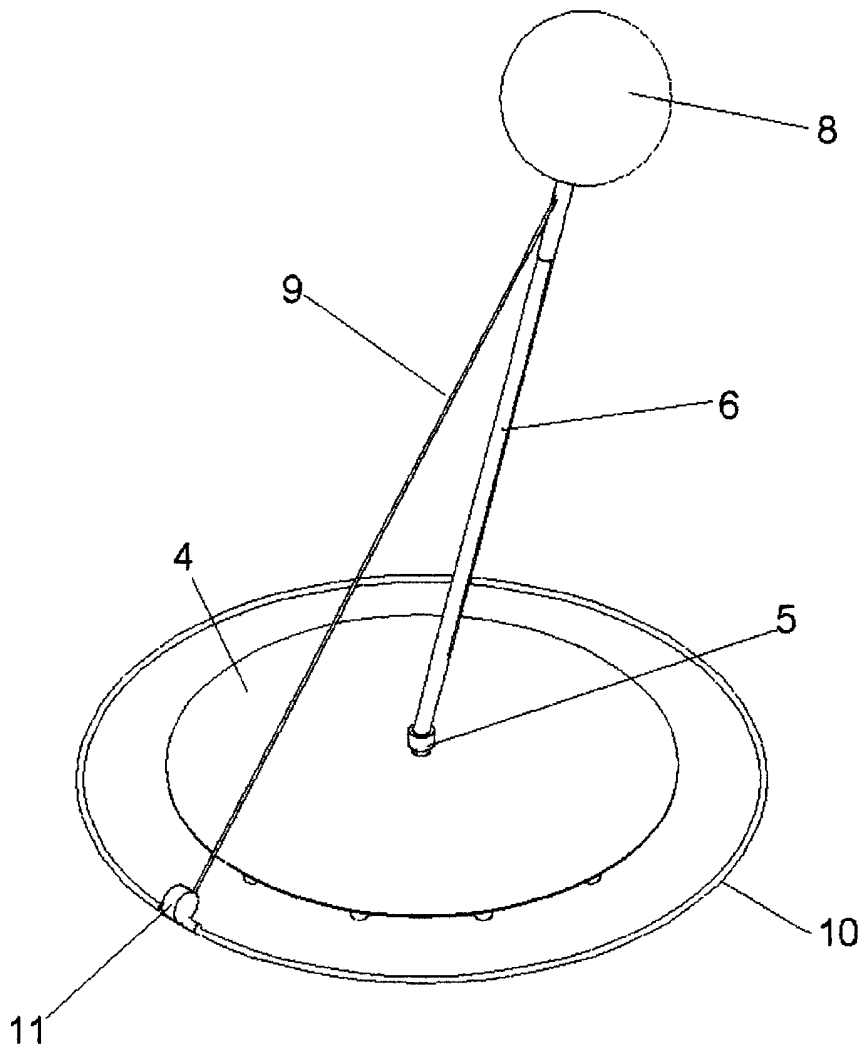
2/10

FIG 2



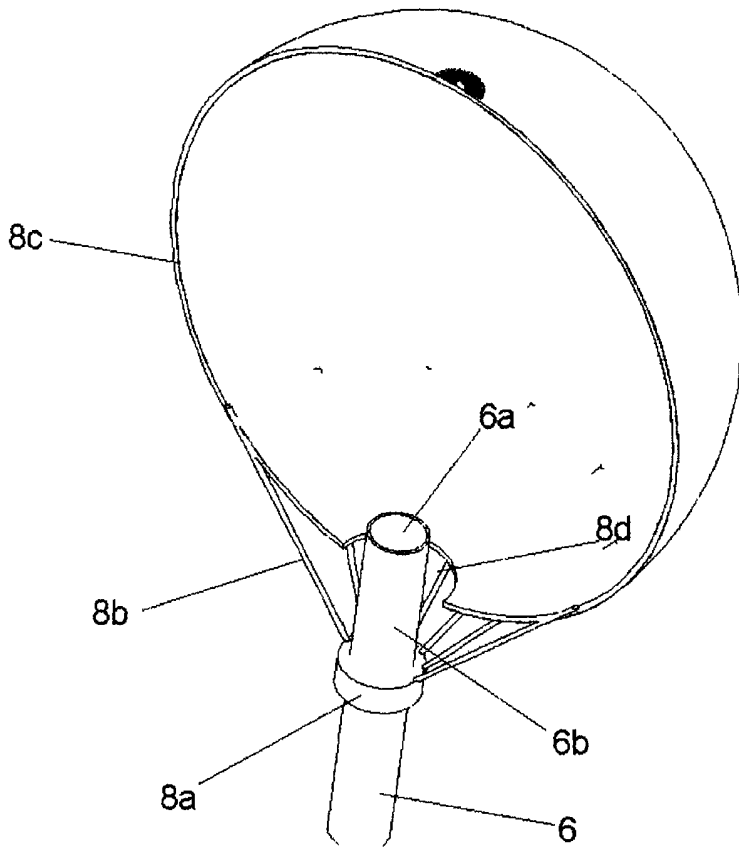
3/10

FIG 3



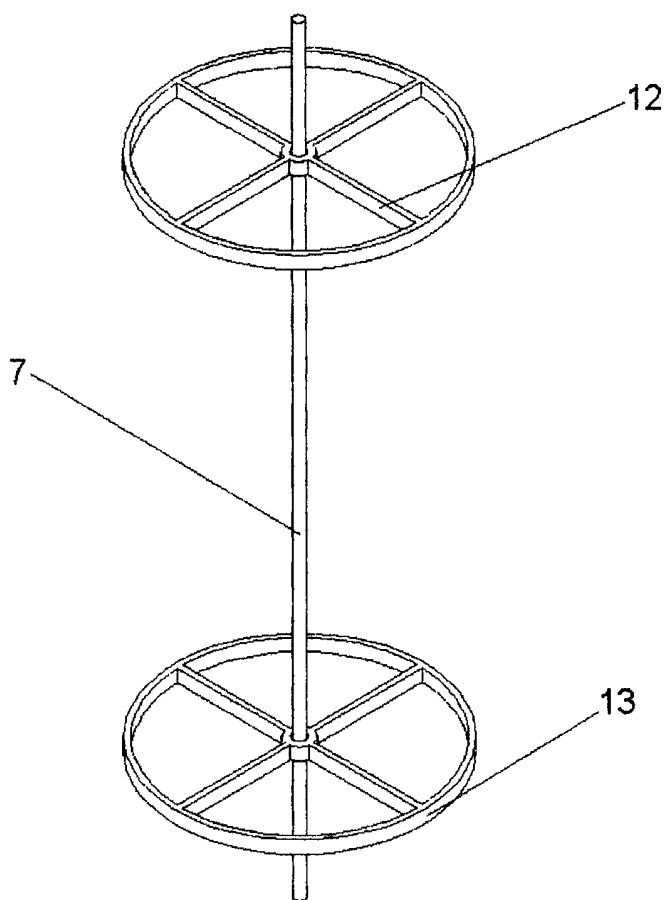
4/10

FIG 4



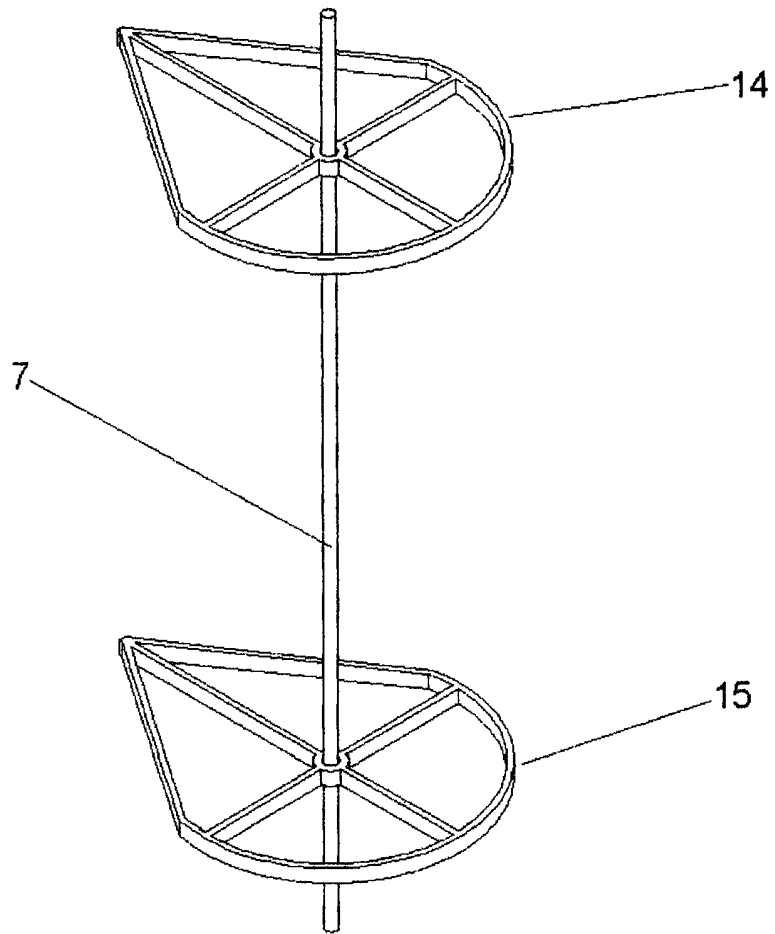
5/10

FIG 5



6/10

FIG 6



7/10

FIG 7

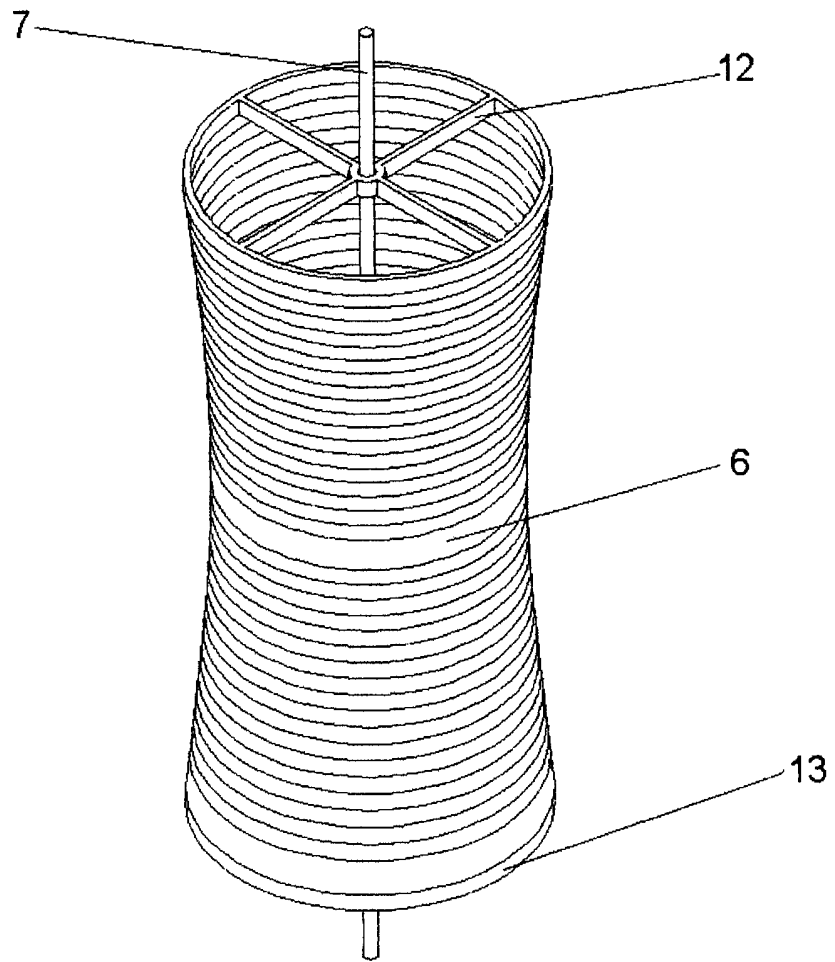




FIG 8

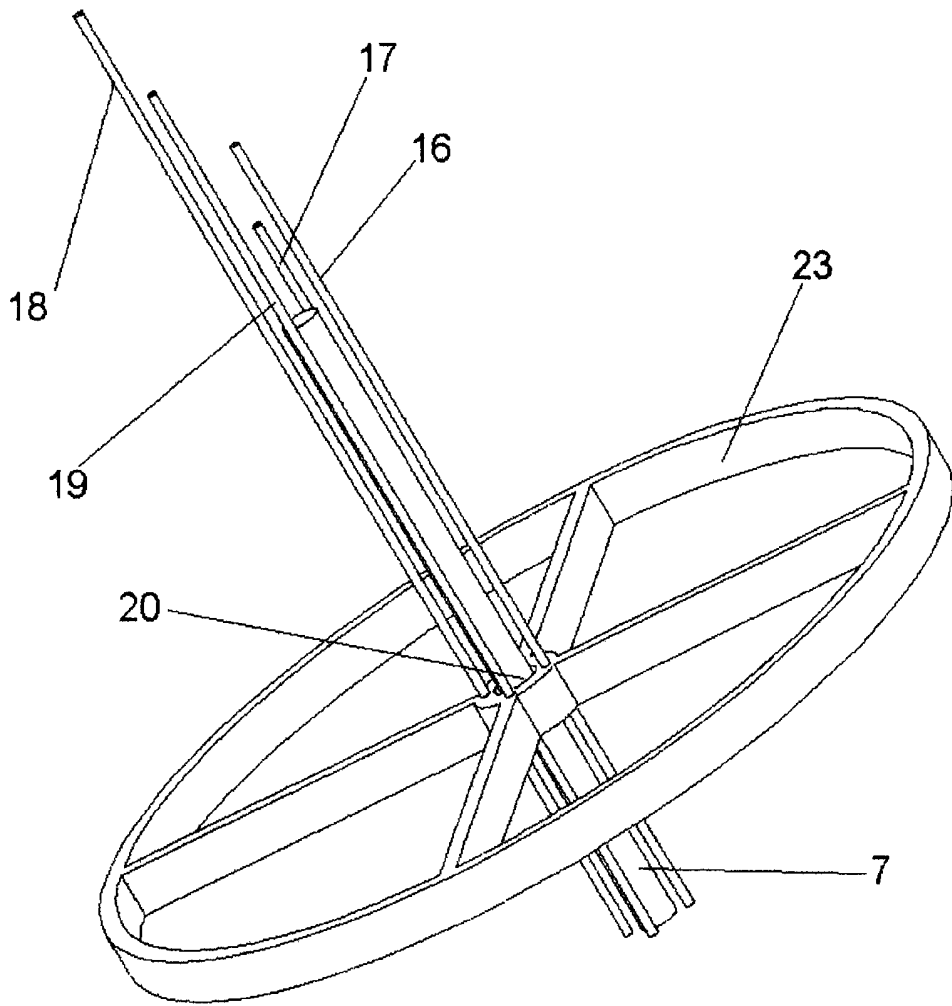
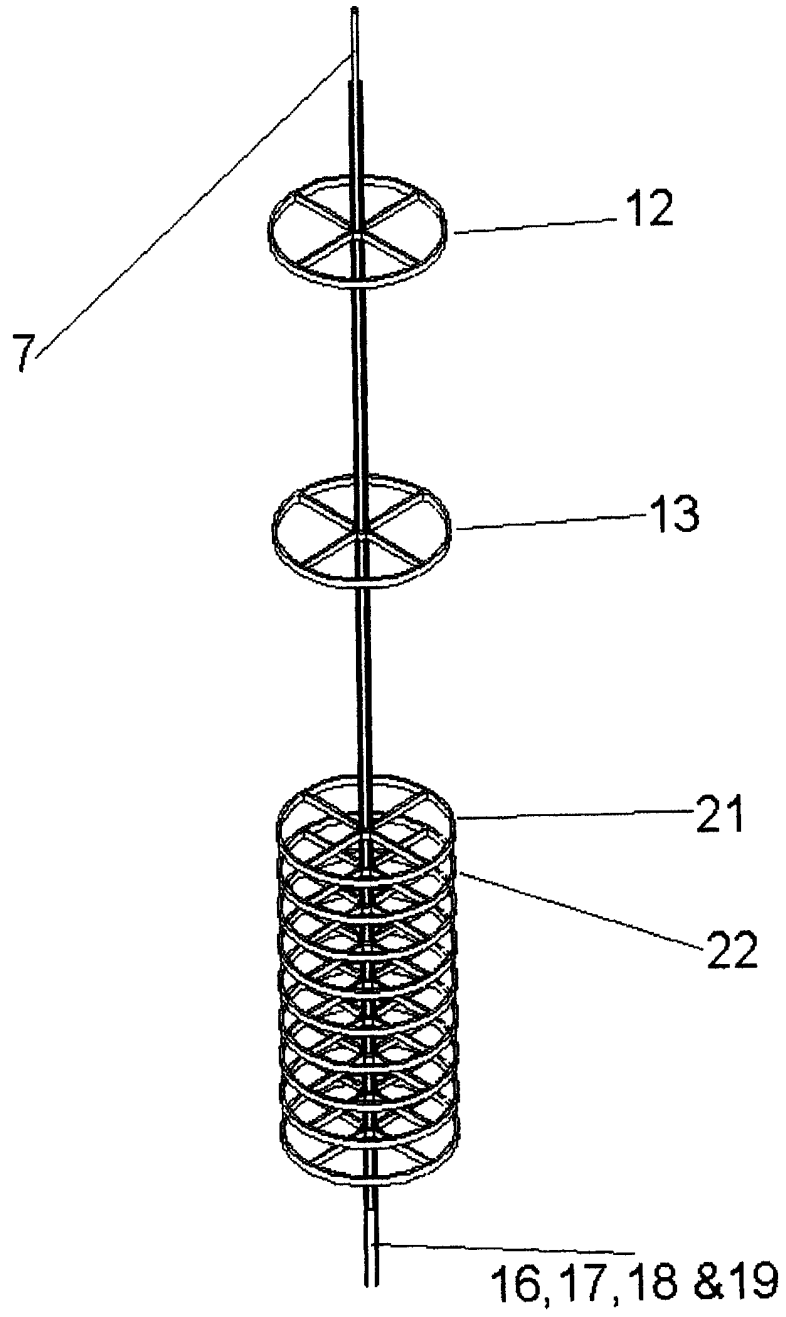
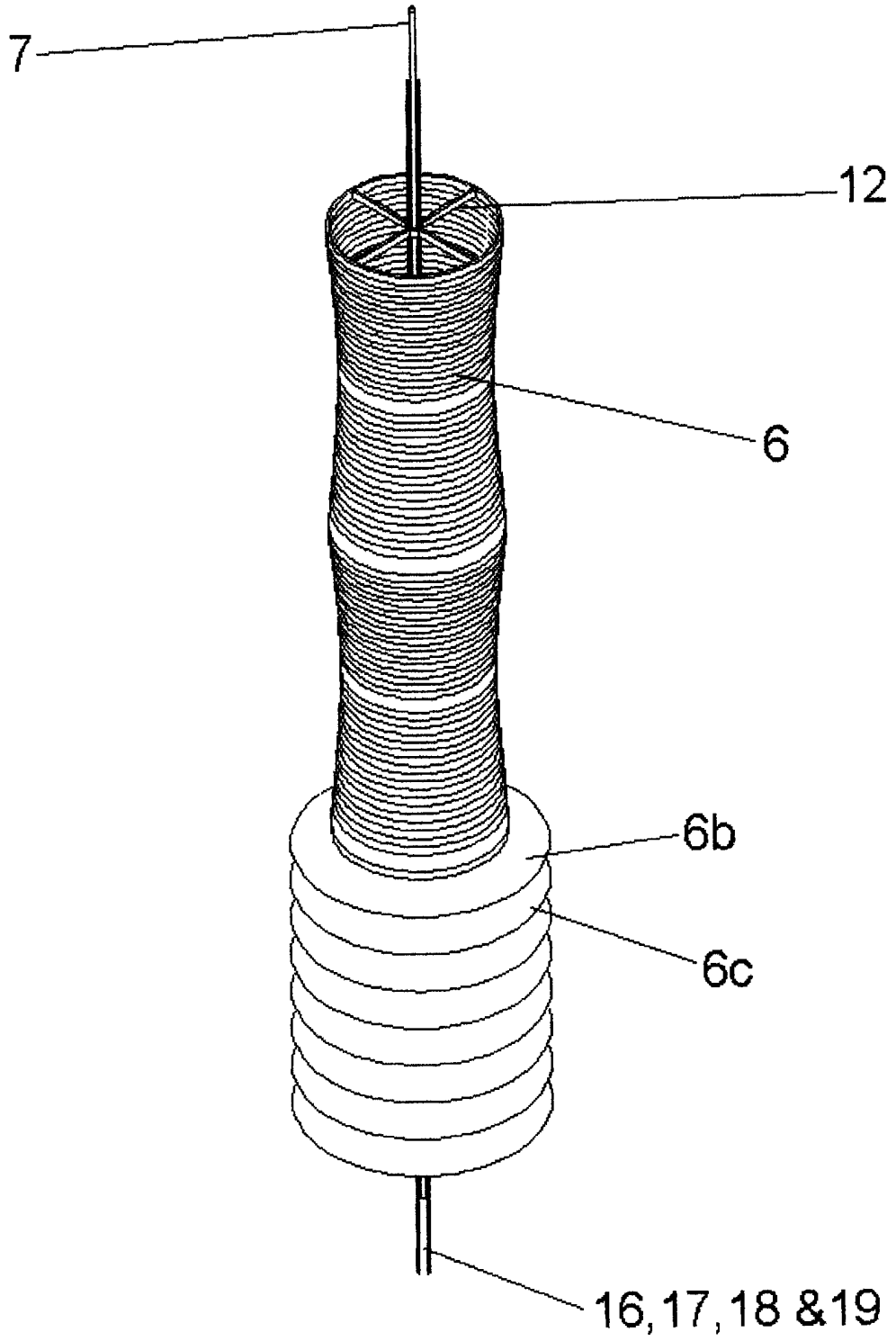


FIG 9



10/10

FIG 10



## Title of the Invention

Balloon Supported Flexible Chimney Especially for Solar Tower Power Stations

## Field of the Invention

A lightweight flexible chimney supported by a tethered balloon for use as an alternative to a free standing chimney in a solar thermal power station.

## Background of the Invention

Conventional solar tower power stations consist of a circular low glazed roof open around its circumference connected to a rigid self supporting chimney. Air is heated in the greenhouse and passes into the chimney via an air turbine which is used to extract mechanical energy to drive an electrical generator. An example of this type of power station was built by Union Electrica Fenosa at Manzanares in Spain and operated between 1982 and 1989 and further details of which are given in an article "The Solar Chimney" by Schlaich Bergemann und Partner on their Web Site at <http://www.sbp.de>

Looking at the basic physics of the chimney the pressure differential from top to bottom can be viewed as the net thrust resulting from difference in weight between the hot gases constrained by its walls and an equivalent column of the cooler gas outside of them.

From this it is clear that either reducing the density of the gases in the chimney or raising its height or both will increase the draft in it.

Although the density can be reduced by raising the temperature of the gases in the chimney the maximum temperature differential that can be supported by the greenhouse collector is limited to few tens of Kelvin as opposed to several hundred Kelvin from a fossil fuelled power plant.

On the other hand doubling the height of the chimney nearly doubles the net force available at the base of the chimney. If this additional force is taken up by the air turbine then extra power can be generated without substantially increasing the rate of air flow in the chimney and hence without the need to provide additional air heating capacity.

Practical solar tower power stations therefore ideally require very high chimneys, however these are expensive to build and vulnerable to both high winds and earthquakes.

The use of balloons to support chimney structures has been proposed, for instance in US 3,974,756, and the use of inflatable buoyant segmented chimneys in DE 3922846 however they lack the specific benefit of active tensioning of the chimney wall to provide additional stability against forces due to the pressure differential across the chimney wall in the case of the former and are more complex and vulnerable to mechanical damage in the latter.

## Object of the Invention

The basic objective of this invention is to provide an improved chimney for use in a solar tower power station.

## Summary of the Invention

A chimney is provided consisting of:

- i) A long tube made of flexible membrane largely impermeable to air.
- ii) A series of spaced apart supporting features along the longitudinal axis, attached to the tube wall, constructed so as to allow the passage of air along said longitudinal axis, which are also attached to one or more tensioning members, extending along the length of interior or exterior the tube, at intervals so as to place the sections of tube wall between the supporting features under sufficient tension to form a continuous air flow gap.
- iii) A balloon, suitably tethered and attached to the tube, capable of providing lift in excess of the combined forces due to the weight of the structure and any tensioning forces applied to the tube wall tensioning system.

## Advantages of the Invention

In a conventional chimney the walls provide not only the barrier between the internal low density gases and the external high density ones, but also the means of supporting the entire structure and preventing its collapse under the pressure differential about its circumference.

By removing the requirement to support the weight of the structure the walls can be very much thinner and hence lighter and cheaper.

However whilst only a very thin membrane is required to provide an impermeable barrier, significant compression forces due to the pressure differential, which is zero at the top and at its largest at the base, mean that such a membrane would be unable by itself to maintain a suitable air flow gap.

Putting such a membrane under tension would make it possible to achieve satisfactory dimensional stability, however the maximum length of tube that could be stabilised in this way would be limited by the tensile strength of the materials used, since the force generated by the pressure differential across the membrane is proportional to its surface area and hence length at fixed diameter.

Thus the invention calls for a repeating structure of supports attached to the membrane and using a tensioning member to transfer tension from an outside source to the membrane. Thus the total load across all of the membrane sections can be carried by the tensioning member which can be much stronger than the membrane, whilst the load on individual sections can be limited by means of controlling the

separation of the support feature to a value that is below yield point of the material from which the membrane is made

Use of a balloon to lift the entire structure also allows its weight to be carried under tension rather than compression again permitting the use of lightweight and flexible materials that nevertheless have great strength in this loading mode.

Since the objective is to provide improved electrical energy extraction from the thermal energy absorbed by the collector structure it is clear that the key advantage of this invention is its ability to maintain a higher pressure differential across the air turbines for a given size of collector than would otherwise be economically viable using conventional chimney construction techniques.

Dealing with very high winds safely is also straightforward with the invention since it can be lowered to ground level until the weather improves. Whilst this does mean the power supply would be interrupted for this period it also means there is no danger of permanent damage to the structure as is the case with conventional chimneys.

The invention is also well suited for use in areas of high earthquake risk since the flexible structure would not be affected by shaking loads and construction of a high resistance mooring is also straightforward.

At present large low circular greenhouses are used as the thermal collector and air heater, which is very simple reliable and cheap. To allow for 24 hour operation simple water storage vessels can be also be placed under the glazing which absorb excess heat during the day and release it then in the evening and at night. Such collectors



are however thermally inefficient meaning that they have to have a very large surface area for any given rated power of the station.

With much higher thermal efficiencies through the increased chimney heights possible it would be economic to use solar water heating panels, feeding a heat exchanger at the base of the chimney mounted either before or after the air turbines via a large storage insulated tank, instead. In this way very precise control of the air flow in the chimney could be achieved and the output of the air turbines adjusted to the variable demand for electricity.

This would be particularly advantageous for small generating plants serving small isolated communities, where excess generating capacity during the day could not be distributed to other users via an electricity grid.

Although more complex the absorber structure could also be physically much smaller and it would be possible to avoid the use of pumps by designing the system to make use of thermal siphoning effects.

## Preferred or Optional Features of the Invention

In its preferred form the invention comprises a hot air balloon utilising the hot air exhaust from the chimney to provide the necessary lift. In this way the power station is self contained and does not require access either to liquid fuels for a conventional hot air balloon or lighter than air gases such as helium.

The simplest and lightest arrangement uses the balloon tether, comprising at least one flexible cord of sufficient strength, as the tensioning member with the support features attached to the tether itself; however if the support features are not reversibly attached to the tether then the chimney structure hinders winding of the tether in a winch system.

This means that raising and lowering of the chimney would involve laying the chimney on its side which would expose it to puncturing hazards and limit the ability of the operator to control the altitude of the balloon. It would also reduce the ease of transfer of hot air from the absorber structure to the balloon until it was in flight meaning that an auxiliary heating system might then be necessary.

In its preferred form the tether is co-axially located within the chimney structure; however, particularly in the case where the supporting features are reversibly attached to the tether system, it can also be provided externally to the chimney structure.

Separating the tensioning and tethering functions does increase the complexity of the chimney itself, but would allow for the use of conventional tethering and winching

equipment to launch, control and recover the balloon and chimney from the centre of the sunlight absorbing structure.

Therefore in the preferred form the supporting features may slide over the central balloon tether with one or more separate tensioning cords attached to them. The ends of these tensioning cords are attached at one end to the balloon and at the other to a suitably anchored device which can adjust the level of tension on them.

Before erection the chimney and support features are threaded over one or more poles or a rigid hollow tube with a continuous air flow gap from the air turbines to the flexible portion of the chimney in a concertina fashion and unfold one after the other as the balloon rises. Once the balloon has reached the extent of the chimney the tensioning cords can be tightened increasing the ability of the structure to maintain the air flow gap against the pressure differential across the chimney wall.

This allows in particular for a larger pressure differential across the air turbine and hence more efficient use of the thermal energy collected.

During launch the air turbines would be so configured as to provide a greatly reduced resistance to the air flow and the chimney so constructed that its weight provides sufficient wall tension to maintain the air flow gap such that adequate hot air can enter the balloon to provide the lift required.

The spacing of the support features would also not be constant in the preferred form since the pressure differential across the chimney wall reduces with height. Therefore the support features would be so arranged that the interval between them is smaller

towards the base and larger towards the top. It is also the case that the membrane need not be of constant thickness along the length of the chimney and can be thinner towards the top than it is at the base.

The support features can be located internally or externally to the membrane or both; but in the preferred form they are internally located and in addition to the tensioning functions already described they also maintain the separation between the chimney and the balloon tether.

Looking at the tethering system it is clear that wind will cause the balloon to be pushed away from its position above the air turbines causing it to descend to a height where the vector sum of the forces generated by the balloon and tether balance those due to the wind resistance of the balloon and chimney.

The addition of a second tether running upwind of the balloon would reduce this effect albeit at the cost of additional weight and complexity, however it would be necessary to make the anchoring feature movable, possibly on a circular rail, so that it can be relocated to take allowance of shifts in the wind direction.

Since the force needed to move the balloon a given amount away from turbines is proportional to the net lift, an alternative to a second tether would be to use a balloon with a significant excess lifting capacity.

It is also possible to minimise the wind drag on the chimney by using support features with a streamlined shape, in particular with a tapered rear side to minimise the generation of turbulence.

It may also be advantageous to be able to supplement the absorbed solar energy at times when the average solar insolation is too small to maintain the desired output of electricity by means of feeding the flue gas from a combustion device capable of burning organic material such as bio-mass to the chimney.

## Brief Description of the Drawings

Figure 1 is a perspective view of a conventional solar tower power station.

Figure 2 is a perspective view of a balloon supported chimney.

Figure 3 is a perspective view of a balloon supported chimney with a secondary wind tether.

Figure 4 is a perspective sectional view of a hot air balloon attached to the chimney.

Figure 5 is a perspective view of circular support features attached to a central tether.

Figure 6 is a perspective view of two support features shaped to reduce the wind resistance of the chimney.

Figure 7 is a perspective view of a section of the chimney showing the membrane stretched between two support features.

Figure 8 is a detailed perspective view of a support feature with four tensioning cords and a central opening to allow it to slide over the balloon tether.

Figure 9 is a perspective view of a set of separately tensioned sliding support features as they unfold during balloon launch.

Figure 10 is a perspective view of that section of the chimney with the membrane attached.

## Detailed Description of the Drawings

Figure 1 shows a conventional solar power station with a low glazed roughly circular green house structure 1 open around its circumference discharging via an air turbine 2 into a rigid self supporting chimney 3.

Referring to figure 2 one aspect of the invention calls for a low glazed structure 4 open around its circumference discharging into an air turbine 5. The chimney provided in this case comprises however a balloon 8 tethered to the ground via a tether 7 which supports a flexible membrane 6 which is held open along its length discharging via opening 6a.

Referring to figure 3 a second tether 9 is provided to improve stability against wind induced forces, with a movable anchoring feature 11 running on a guide rail 10. The membrane 6 in this case extends to base of the balloon 8 hiding the primary tether 7 from view, but allowing the balloon 8 access to the hot air rising through the structure.

Referring to figure 4 this can be seen in more detail where the balloon envelope 8c is attached to a ring 8a, via a series of cords 8b, which in its turn is attached to both the end of the flexible tube 6 and the balloon tether 7. Hot air rising up the chimney passes through this ring and along a portion of the tube 6b extending up into the balloon envelope through the opening 8d into the balloon envelope 8c. Since the opening 8d is larger than the connecting section of chimney 6c air leaving the chimney within the balloon itself displaces cooler air at the bottom of the inflated envelope through said opening 8d.

In this way the air within the envelope is continuously renewed with hot air from the solar thermal collector 4 maximising lift.

Referring to figure 5 a pair of membrane support features 12 and 13 are attached to the balloon tether 7. Once fully tensioned the section of tether between them defines the maximum separation that they can achieve. Since these support features are intended to be mounted within the membrane 6 they have an open spoked form which provides very low resistance to the flow of air along the chimney.

Although the circular form which these support features give the chimney the best cross-section to weight ratio and lowest back pressure for a given radial extent, this shape also has the highest drag meaning that it will also maximise wind imposed loading of the structure. Modifications to the shape of the support features and hence shape of the chimney can reduce this and an example of a pair of these features 14 and 15 directly attached to the tether 7 is shown in figure 6.

Referring to figure 7 once the tensioning member 7 is pulled taut the membrane 6 is stretched between the support features 12 and 13 to which it is suitably attached taking up a curved shape under the compression forces due to the pressure differential between the interior and exterior of the chimney.

An example of a support feature 23 that can slide on the balloon tether 7 which passes through clearance opening 20 is shown in figure 8. The tensional forces required to counteract the compression loading of the membrane are provided in this case by four tensioning cords 16,17,18 & 19 which are attached to and pass through the support feature.



During launch and recovery of the balloon these support features can concertina together with the main balloon tether 7 being wound on a winch as shown in figure 9. Looking at the membrane 6 in figure 10 it can be seen that this likewise folds to a very compact structure.

## Claims

1. A chimney comprising a long flexible tube made of a membrane largely impermeable to air providing a continuous air flow gap from one end supported by a suitably tethered balloon, capable of providing lift in excess of the combined forces due to the weight of the structure and any tensioning forces applied to the tube wall tensioning system, to the other end where it is attached to an air heating feature, and one or more air turbines, which extract mechanical energy from the air flowing in the system due to the pressure differential between the exterior and interior of the chimney.
2. A chimney as defined in claim 1 where the tube membrane is attached to and supported by a series of longitudinally spaced apart support features, so constructed as to not block the air flow gap, which are located either internally or externally to the air flow gap and are attached to a tensioning member comprising one or more flexible elements, which transfer sufficient force deriving from the net lift of the balloon to the sections of walls between the support features so as to maintain the air flow gap along the length of the chimney against the pressure differential acting across the membrane.
3. A chimney as defined in claim 2 where the balloon tethering and support feature anchoring functions are provided by a single flexible assembly or member.
4. A chimney as defined in claim 2 where the balloon tethering and support feature anchoring functions are provided by separate flexible assemblies or members both of which are connected to the balloon such that the support features can

move relative to the tethering assembly and so that both tethering and tensioning assemblies can be independently tensioned against the net lift of the balloon and forces acting on the membrane.

5. A chimney as defined in claim 4 where the length of the balloon tether can be adjusted by means of a winch.
6. A chimney as defined in claim 4 where the tension in the tensioning assembly can be adjusted by means of a winch.
7. A chimney as defined in any of the preceding claims where the first portion of the chimney is provided by a rigid hollow cylinder to which the flexible portion is then attached.
8. A chimney as defined in any of the previous claims where air at a temperature higher than the air outside the balloon envelope is discharged into the interior of the balloon envelope from the top opening of the chimney.
9. A chimney as defined in any of the previous claims where thermal energy for the air heating feature is provided by sunlight absorbed under a low circular glazed structure open at its circumference and provided with a discharge opening in the centre to which the air turbine and chimney are attached.
10. A chimney as defined in any of claims 1 to 8 where thermal energy for the air heating feature is provided by water heated by sunlight absorbed by a system containing solar water heating panels.

11. A chimney as defined in any of claims 1 to 8 where thermal energy for the air heating feature is provided the combustion of organic material in air.



INVESTOR IN PEOPLE

**Application No:** GB 0317706.0  
**Claims searched:** All

**Examiner:** M C Monk  
**Date of search:** 11 December 2003

### Patents Act 1977 : Search Report under Section 17

#### Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1,8,9 at least	DE 29622549 U THOMAS DRABNER See also the enclosed Abstract & Figs.1 & 2; balloon (7) holds up chimney (2) in a solar power station for generating electricity; tensioning wire (10); tensioning arrangement (48,50 Fig.5).
A		JP2003056211 TSUTOMU ODAWARA Balloon holding up a flue for a sewage treatment plant.

#### Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application

#### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>v</sup>:

F4J; F4U

Worldwide search of patent documents classified in the following areas of the IPC<sup>7</sup>:

E04H; F23J; F23L

The following online and other databases have been used in the preparation of this search report:

ONLINE DATABASES: WPI, EPODOC, JAPIO