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(54) **Title:** TRANSPIRED SOLAR COLLECTOR

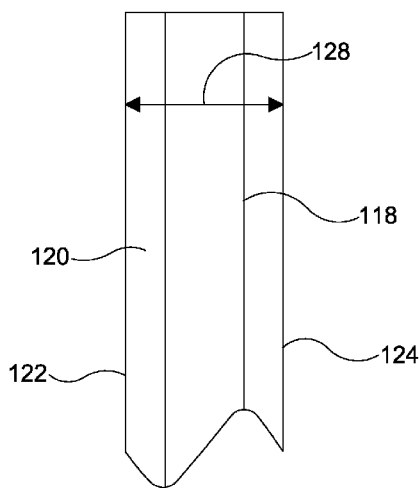


FIG. 2

(57) **Abstract:** A transpired solar collector (100) comprising: an absorber panel (108) having a body (118) formed of stainless steel; a surface layer (120) of chromium oxide on an exterior face (122) of the body (118); and a plurality of through-holes (110) formed through the body (118) and surface layer (120), wherein the surface layer (120) has a thickness (126) of at least 70 nanometres.





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## TRANSPIRED SOLAR COLLECTOR

The present invention relates to a transpired solar collector.

5 With improvements in building construction leading to increasingly air tight buildings, it has become increasingly important to provide ventilation systems to cycle fresh air through the building. Where the fresh air being introduced is colder than the warm air being expelled, the temperature inside the building can be lowered. This means the building may require heating.

10

US 4 899 728 discloses a system in which ventilation air for a building is pre-heated by providing on a south-facing wall a solar-energy absorbent collector panel with a plurality of air-inlet openings which communicate with air collection channels behind the panel. Outside air passing upwardly along the panel is heated by the heat of the panel which itself is heated by a combination of solar radiation and heat being lost  
15 from the interior of the building. The outside air, passing the short distance along the panel to the closest air inlet opening, is withdrawn therethrough into the air collection channel and expelled into the interior of the building. The type of solar collector described in US 4 899 728 has become known as a transpired solar collector.

20

Transpired solar collectors can be used to preheat the air introduced to the building, thus reducing the heating required to be contributed by standard heating systems. Transpired solar collectors can also be used to provide pre-heated air for other applications.

25

The heat provided by a transpired solar collector is captured from freely available solar energy (a renewable energy source). The only external power required for a transpired solar collector is the power required to drive the air circulation system (such as a fan). Standard heating systems, on the other hand, require significant  
30 external power to provide heating. External power (for the air circulation system or standard heating system) may be generated from fossil fuels (such as coal or gas), nuclear sources or renewable sources. Therefore, using a transpired solar collector can reduce the amount of external power required, reducing costs. Also, where the external power is provided by fossil fuels or nuclear sources, there are significant  
35 environmental benefits, and use of depleting supplies is reduced.

However, the efficiency of transpired solar collector systems is limited by radiation heat losses from the transpired solar collector material to atmosphere. Such radiation heat losses are a result of the low temperature of the surroundings compared to the transpired solar collector, and increase significantly as the temperature of the transpired solar collector increases. The radiation heat losses also limit the temperature increase of the transpired solar collector material, and of the outside air heated by it. This limits the applications for which the supply of heated air can be used.

10

Furthermore, transpired solar collectors are typically constructed using mild steel or aluminium and generally feature a coating of paint, usually dark, so as to increase the proportion of solar energy absorbed. These coatings are susceptible to fading and degradation over time through exposure to ultraviolet light, limiting the life expectancy of the transpired solar collectors.

15

According to a first aspect of the invention, there is provided a transpired solar collector comprising: an absorber panel having a body formed of stainless steel; a surface layer of chromium oxide on an exterior face of the body; and a plurality of through-holes formed through the body and surface layer, wherein the surface layer has a thickness of at least 70 nanometres.

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The thickened layer of chromium oxide provides the transpired solar collector absorber panel with the properties of low emissivity and high absorbance (i.e. it forms a selective absorber). Therefore, the transpired solar collector is more efficient than other transpired solar collectors, meaning that it converts a higher proportion of the solar radiation falling on a given area of the absorber panel into useful heat energy. The absorber panel also has high resistance to corrosion, meaning the collector has a long lifetime. Furthermore, as the chromium oxide is an integral part of the chemical structure of the absorber panel rather than being a painted coating, and is durable in ultraviolet light, it is not susceptible to fading or peeling.

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In addition, the transpired solar collector is able to heat the air passing through it to hotter temperatures, and so the pre-heated air can be used in applications other than building ventilation.

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The surface layer may have a thickness of between 70 nanometres and 400 nanometres. Preferably, the surface layer may have a thickness of between 100 nanometres and 280 nanometres.

5

The thickness of the surface layer may be arranged to determine the appearance of the transpired solar collector. The thickness of the surface layer may determine the colour of the transpired solar collector.

10 Using the thickness to control the appearance and/or colour provides an aesthetically pleasing appearance, while still achieving a high efficiency absorber panel. The colour is also durable in ultraviolet light, meaning the colour also has a long lifetime.

The absorber panel may have an emissivity of no more than 0.30. The absorber panel  
15 may have an emissivity of between 0.10 and 0.30. The absorber panel may have an emissivity of between 0.10 and 0.26.

The absorber panel may have a solar absorptivity of at least 0.50. The absorber panel  
may have a solar absorptivity of between 0.50 and 0.90.

20

The surface layer may form an exterior surface of the transpired solar collector.

The transpired solar collector may further comprise: a rear panel, spaced from the absorber panel, defining a cavity between the absorber panel and the rear panel, the  
25 surface layer being outside of the cavity.

The rear panel may be formed by the wall or roof of a building.

The surface layer may be a chemically or electrochemically thickened layer of  
30 chromium oxide.

According to a second aspect of the invention, there is provided a stainless steel transpired solar collector having a chemically or electrochemically thickened chromium oxide surface layer.

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The second aspect may include any one or more of the optional features of the first aspect.

5 According to a third aspect of the invention, there is provided a building comprising the transpired solar collector of the first or second aspect, the transpired solar collector being mounted on the wall or roof of the building such that the surface layer forms the exterior surface of the building.

10 According to a fourth aspect of the invention, there is provided a method of manufacturing a transpired solar collector, the method comprising: providing a stainless steel plate, the stainless steel plate having an original chromium oxide layer on a first surface (typically an inherent, naturally occurring, chromium oxide layer); chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer; forming a plurality of  
15 through-holes through the stainless steel plate; and forming the stainless steel plate as an absorber panel of a transpired solar collector, the thickened chromium oxide layer forming an exterior surface of the transpired solar collector, wherein the step of chemically or electrochemically thickening the original chromium oxide can occur before or after the step of forming a plurality of through-holes.

20

The step of chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer may comprise: chemically or electrochemically thickening the chromium oxide layer on the first surface, to form a thickened chromium oxide layer having a thickness of at least 70  
25 nanometres.

The step of chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer may comprise: chemically or electrochemically thickening the chromium oxide layer on the first  
30 surface, to form a thickened chromium oxide layer having a thickness of between 70 nanometres and 400 nanometres.

35 Preferably, the step of chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer may comprise: chemically or electrochemically thickening the chromium oxide layer

on the first surface, to form a thickened chromium oxide layer having a thickness of between 100 nanometres and 280 nanometres.

5 The method may further comprise: forming a transpired solar collector by mounting the absorber panel on the roof or wall of a building, wherein the absorber panel is spaced from the roof or wall, to define a cavity between the absorber panel and the roof or wall; and wherein the surface layer forms an exterior surface of the building.

10 Alternatively, the method may further comprise forming a transpired solar collector by providing a rear panel, spaced from the absorber panel to define a cavity, the surface layer being outside of the cavity.

There now follows, by way of example only, description of embodiments of the invention, described with reference to the accompanying drawings, in which:

15

**Figure 1** illustrates in cross section an example embodiment of a transpired solar collector formed on the exterior of a building, as part of a building ventilation system;

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**Figure 2** illustrates an example embodiment of a cross section through an absorber panel according to the invention;

**Figure 3** illustrates an example method for manufacturing a transpired solar collector;

25

**Figure 4** illustrates an example embodiment of the front of an absorber panel according to the invention; and

30

**Figure 5** illustrates an example of the improvement that can be achieved by using transpired solar collectors with chemically or electrochemically thickened chromium oxide layers.

Figure 1 shows an example of a transpired solar collector 100. The transpired solar collector 100 is arranged on the exterior 102 of the building, and has an absorber panel 108 (absorbing collector panel) mounted onto the wall 106 of the building, by

35

brackets (not shown). A plurality of through-holes 110 (perforations) are formed through the absorber panel 108.

The absorber panel 108 is spaced from the wall 106 so that a cavity 112 is defined  
5 between the absorber panel 108 and the wall 106. The cavity 112 is connected to ducting 114 of a ventilation system configured to provide fresh air into the interior 104 of the building.

In use, the absorber panel 108 absorbs solar energy, heating the material of the  
10 absorber panel 108. A boundary layer adjacent to the exterior (front) surface 122 of the absorber panel 108 is heated by the absorber plate 108 and is drawn through the through-holes 110 into the cavity 11 and is further drawn from within the cavity 112 to outlet ducting 114 by use of an air-moving fan 116. The air flow through the absorber panel 108 and ventilation system is shown by the arrows in Figure 1.

15

Figure 2 shows a cross-section of the absorber panel 108 according to embodiments of the invention. The absorber panel 108 is made of stainless steel. As is known, stainless steel is an alloy of steel containing chromium. Stainless steel has an oxidation surface of chromium oxide (for example  $\text{Cr}_2\text{O}_3$ ) on its surface. Under normal  
20 circumstances, the oxidation surface is between 1 and 8 nanometres thick, and is not usually more than 10 nanometres thick.

The absorber panel 108 shown in Figure 2 has a chromium oxide layer that has been chemically or electrochemically thickened. In one example, the stainless steel  
25 absorber panel is immersed in a hot solution containing chromic acid and sulphuric acid. The thickened chromium oxide layer is formed on both faces of the panel 108. This process was first disclosed in US 4 071 416, although it has not been used in materials for transpired solar collectors.

30 The absorber panel can be considered to be formed from a body 118 of stainless steel and an integral surface layer 120 of chromium oxide on the front surface 122 of the panel and on the rear surface 124 of the absorber panel 108.

The chromium oxide layer surface layer 120 should have a thickness 126 of greater  
35 than 70 nanometres. The thickness 126 should also be less than 400 nanometres. In



one example, the thickness is chosen to be between 100 and 280 nanometres. The overall thickness 128 of the absorber panel is between 0.5 millimetres and 2 millimetres .

- 5 For the wavelengths of light comprising solar energy, stainless steel with a thickened chromium oxide surface layer has high solar absorptivity and low emissivity, making it a selective material.

10 For the wavelengths of light comprising solar energy, stainless steel with a thickened chromium oxide surface layer has high solar absorptance (in the wavelength 0 nm to 3000 nm) and low long-wave emittance (> 3000 nm), making it a selective material.

15 For stainless steel with a surface layer between 70nm and 400 nm, the solar absorptivity of the absorber panel 108 is between 0.50 and 0.90 and the emissivity is between 0.10 and 0.30. The solar absorptivity and emissivity is dependent on the thickness of the surface layer 120.

20 The surface layer thickness 126 also influences the colour of the absorber panel 108, and so the colour can be chosen by choosing the thickness, providing an aesthetic effect. For example, a layer of 70 nanometres thick provides a bronze colour, and a layer of 130 nanometres provides a blue colour. The surface may also be patterned. For example, the surface may be patterned by polishing and/or cold rolling.

25 The colour is a result of the structure of the surface layer 120, and therefore is not vulnerable to fading and so on. The surface layer 120 is also resistant to corrosion. These factors mean that the absorber panel 108 can have a lifetime of up to 100 years, and no further external surface protection is required; the surface layer 120 can form the external layer open to the atmosphere.

30 Figure 3 shows an example embodiment for a method 200 of manufacturing a transpired solar collector 100.

35 At a first step 202, a sheet of stainless steel is provided, which has an inherent original chromium oxide layer on its surfaces. The chromium oxide layer 122 of the sheet is then chemically or electrochemically thickened 204. Through-holes 110 are

then formed 206 and finally 208, the sheet is provided as the absorber panel 108 in a transpired solar collector 100.

The holes may be formed 206 before or after the chromium oxide layer is thickened  
5 204. Also, it will be appreciated that the sheet may be cut to the desired size at any stage in the process 200.

Figure 5 illustrates an example of the improvement that can be obtained by using  
10 transpired solar collectors 100 with chemically or electrochemically thickened chromium oxide layers.

Figures 5(a) to 5(d) show the air temperature rise achieved with a standard transpired solar collector with a black surface covering 302, compared to transpired solar collectors 100 with chemically or electrochemically thickened chromium oxide layers.  
15 The air temperature rise is shown for a transpired solar collector with a black finish 304 and a blue finish 306.

The air temperature rise is shown as a function of the solar radiation falling on a given area of transpired solar collector 100. By way of example, at dusk or dawn,  
20 approximately, the solar radiation is approximately 200 Watts per square metre, in moderate sun, the solar radiation is approximately 600 Watts per square metre, in high sun, the solar radiation is approximately 1 000 Watts per square metre and in the dark, the solar radiation is 0 Watts per square metre. With solar collectors, the solar radiation experienced by the absorber panel 108 can be up to 1 200 Watts per square  
25 metre, and maybe higher by concentrating the incident solar radiation with reflective surfaces adjacent to the absorber panel 108.

In all cases, the transpired solar collector has an area of 300 square metres. In Figure 5(a), the air temperature rise is shown for an air flow rate of 5.25 kilograms per second (a lower air flow rate is used to obtain higher air temperatures), ambient air  
30 temperature of 0 °C, and outside air temperature of -10 °C. In Figure 5(b), the air temperature rise is shown for an air flow rate of 5.25 kilograms per second, ambient air temperature of 25 °C, and outside air temperature of 15 °C. In Figure 5(c), the air temperature rise is shown for an air flow rate of 14 kilograms per second (a lower air  
35 flow rate is used to obtain higher air temperatures), ambient air temperature of 0 °C,

and outside air temperature of  $-10\text{ }^{\circ}\text{C}$ . In Figure 5(d), the air temperature rise is shown for an air flow rate of 14 kilograms per second, ambient air temperature of  $25\text{ }^{\circ}\text{C}$ , and outside air temperature of  $15\text{ }^{\circ}\text{C}$ .

- 5 From Figures 5(a) to 5(d) it can be seen that for a range of operating conditions, the transpired solar collector 100 with a chemically or electrochemically thickened layer is able to heat air to a higher temperature, meaning it operates more efficiently.

Figure 4 shows an example of the front surface 122 of a section of an absorber panel 108. In the example shown, the through-holes 110 are circular, and provided in a regular grid pattern. However, it will be appreciated that the through-holes may be any shape and arranged in any pattern. It will also be appreciated that a through-hole may be any opening that passes through the absorber panel 108 between the rear surface 124 and the front surface 122. In some examples, holes may be drilled holes, punched holes, punch-rolled slits or any other suitable opening.

The holes may also be any size and there may be any number of holes. For example, each hole may have an area between 0.15 and 15 square millimetres and be spaced by between 5 millimetres and 30 millimetres. The holes may be arranged in a square grid, a triangular grid, or any suitable arrangement.

In the example shown in the Figures, the cavity 112 is formed between the rear surface 124 of the absorber panel 108, and the wall 106 of the building. However, it will be appreciated that the cavity 112 may be formed separately from the wall 106, by a rear panel (not shown). The whole transpired solar collector 100 is then mounted externally on the building.

Whether the cavity is formed by the wall 106, or a rear panel, it will be appreciated that the edges between the wall 106/rear panel may be sealed, although this is not essential.

When used with a building ventilation system, the transpired solar collector 100 may be provided on any suitable surface of the building. For example, the transpired solar collector may be provided on a wall 106 or roof, and the wall 106 or roof may be facing in any direction. In one example, the transpired solar collector 100 may be

arranged to face South, to maximise the amount of solar radiation falling on its surface.

When used on a surface of a building, the low emissivity surface 120 of the absorber panel 108 may act to prevent heat escaping from the building, thus acting as extra  
5 insulation in the winter. The absorber panel 108 may also act as additional shading in the summer, reducing the amount of cooling required.

Alternatively the transpired solar collector 100 may be provided as a separate unit, not  
10 mounted on the building at all. In this situation, ducting connects the transpired solar collector 100 to the building ducting 114.

The ventilation system shown in Figure 1 is shown by way of example; the building  
may have any suitable ducting and any suitable air circulation system.

15

Any of the examples of transpired solar collectors discussed above in respect of a building ventilation system may also be used in applications other than pre-heating air for a building ventilation system.

20 For example, air preheated by the transpired solar collector 100 can be used in the following other situations:

- As a supply of heated air for provision of heating either directly or indirectly, via a heat exchanger or heat pump, for the regeneration of desiccant within a cooling, dehumidification or air-conditioning system,  
25 thereby improving the energy efficiency of desiccant cooling, dehumidification or air-conditioning respectively;
- As a supply of heated air for provision of heating either directly or indirectly, via a heat exchanger or heat pump, for space heating in buildings;
- 30 - As a supply of heated air for provision of heating either directly or indirectly, via a heat exchanger or heat pump, for water heating in buildings;
- As a supply of heated air for provision of heating either directly or indirectly, via a heat exchanger or heat pump, for process heating in  
35 industries requiring heat, including for drying, thawing, evaporation,

distillation and blanching in the food and beverage sectors and for surface treatment and painting in the textile, metals and plastics industries;

- 5 - As a supply of heated air for provision of humidification either directly or indirectly to a humidifier, for space air-conditioning or process humidification;
- As a supply of heated air for provision of heating either directly or indirectly to absorption cooling systems, for space or industrial cooling;
- As a supply of heated air for provision of heating either directly or indirectly to adsorption cooling systems, for space or industrial cooling.
- 10 - For any other situation where heated air is required.

It will be appreciated that the absorber panel 108 may be of any shape and size. Furthermore, a transpired solar collector 100 may be made to cover a large area by using multiple absorber panels 108 to cover the area.

15

It will also be appreciated that the process described above for thickening the surface layer (using a hot solution containing chromic acid and sulphuric acid) is by way of example only, and any suitable process may be used. In some examples, the surface layer may only be thickened on the front face 122 of the absorber panel 108.

20

It will further be appreciated that features which are described in different embodiments may be combined in a single embodiment. Similarly, where several features are described in combination in a single embodiment, such features may also be provided separately or in suitable sub-combinations.

25

**CLAIMS**

1. A transpired solar collector comprising:
  - an absorber panel having a body formed of stainless steel;
  - 5 a surface layer of chromium oxide on an exterior face of the body; and
  - a plurality of through-holes formed through the body and surface layer, wherein the surface layer has a thickness of at least 70 nanometres.
- 10 2. The transpired solar collector of claim 1, wherein the surface layer has a thickness of between 70 nanometres and 400 nanometres.
3. The transpired solar collector of claim 2, wherein the surface layer has a thickness of between 100 nanometres and 280 nanometres.
- 15 4. The transpired solar collector of any preceding claim, wherein the thickness of the surface layer is arranged to determine the appearance of the transpired solar collector.
- 20 5. The transpired solar collector of claim 4, wherein the thickness of the surface layer determines the colour of the transpired solar collector.
6. The transpired solar collector of any preceding claim, wherein the absorber panel has an emissivity of no more than 0.30.
- 25 7. The transpired solar collector of claim 6, wherein the absorber panel has an emissivity of between 0.10 and 0.30.
8. The transpired solar collector of any preceding claim, wherein the absorber panel has a solar absorptivity of at least 0.50.
- 30 9. The transpired solar collector of any preceding claim, wherein the absorber panel has a solar absorptivity of between 0.50 and 0.90.

10. The transpired solar collector of any preceding claim, wherein the surface layer forms an exterior surface of the transpired solar collector.
11. The transpired solar collector of any preceding claim, further comprising:  
5 a rear panel, spaced from the absorber panel, defining a cavity between the absorber panel and the rear panel, the surface layer being outside of the cavity.
12. The transpired solar collector of claim 11, wherein the rear panel is formed by  
10 the wall or roof of a building.
13. The transpired solar collector of any preceding claim, wherein the surface layer is a chemically or electrochemically thickened layer of chromium oxide.
- 15 14. A building comprising the transpired solar collector of any preceding claim, the transpired solar collector being mounted on the wall or roof of the building such that the surface layer forms the exterior surface of the building.
- 20 15. A method of manufacturing a transpired solar collector, the method comprising:  
providing a stainless steel plate, the stainless steel plate having an original chromium oxide layer on a first surface;  
chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide  
25 layer;  
forming a plurality of through-holes through the stainless steel plate;  
and  
forming the stainless steel plate as an absorber panel of a transpired solar collector, the thickened chromium oxide layer forming an exterior  
30 surface of the transpired solar collector,  
wherein the step of chemically or electrochemically thickening the original chromium oxide can occur before or after the step of forming a plurality of through-holes.

16. The method of claim 15, wherein the step of chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer comprises:

5 chemically or electrochemically thickening the chromium oxide layer on the first surface, to form a thickened chromium oxide layer having a thickness of at least 70 nanometres.

17. The method of claim 15, wherein the step of chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer comprises:

10 chemically or electrochemically thickening the chromium oxide layer on the first surface, to form a thickened chromium oxide layer having a thickness of between 70 nanometres and 400 nanometres.

18. The method of claim 17, wherein the step of chemically or electrochemically thickening the original chromium oxide layer on the first surface to form a thickened chromium oxide layer comprises:

15 chemically or electrochemically thickening the chromium oxide layer on the first surface, to form a thickened chromium oxide layer having a thickness of between 100 nanometres and 280 nanometres.

19. The method of any of claims 15 to 18, further comprising:

forming a transpired solar collector by mounting the absorber panel on the roof or wall of a building,

25 wherein the absorber panel is spaced from the roof or wall, to define a cavity between the absorber panel and the roof or wall; and

wherein the surface layer forms an exterior surface of the building.

30

20. The method of any of claims 15 to 18, further comprising:

forming a transpired solar collector by providing a rear panel, spaced from the absorber panel to define a cavity, the surface layer being outside of the cavity.

35



21. A stainless steel transpired solar collector having a chemically or electrochemically thickened chromium oxide surface layer.

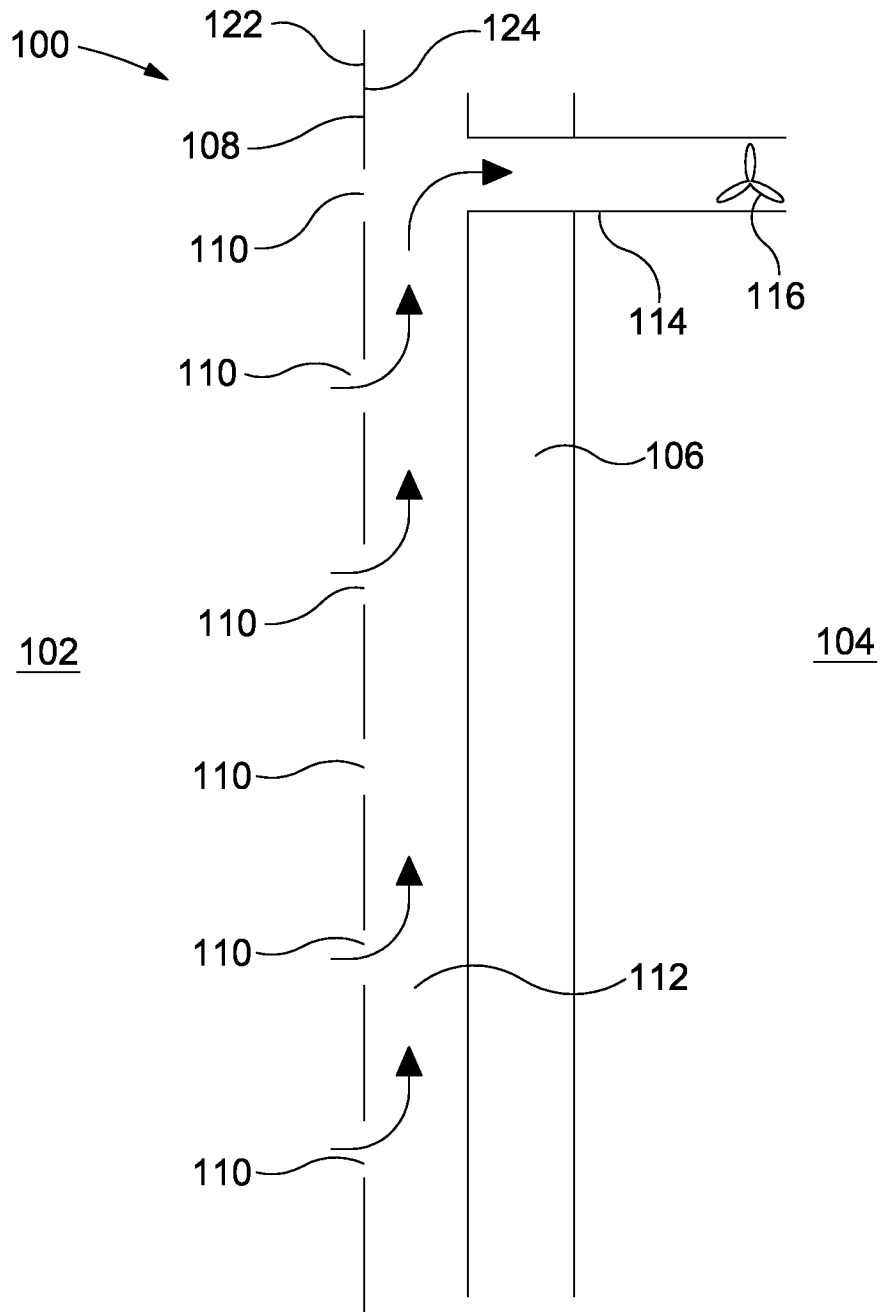


FIG. 1

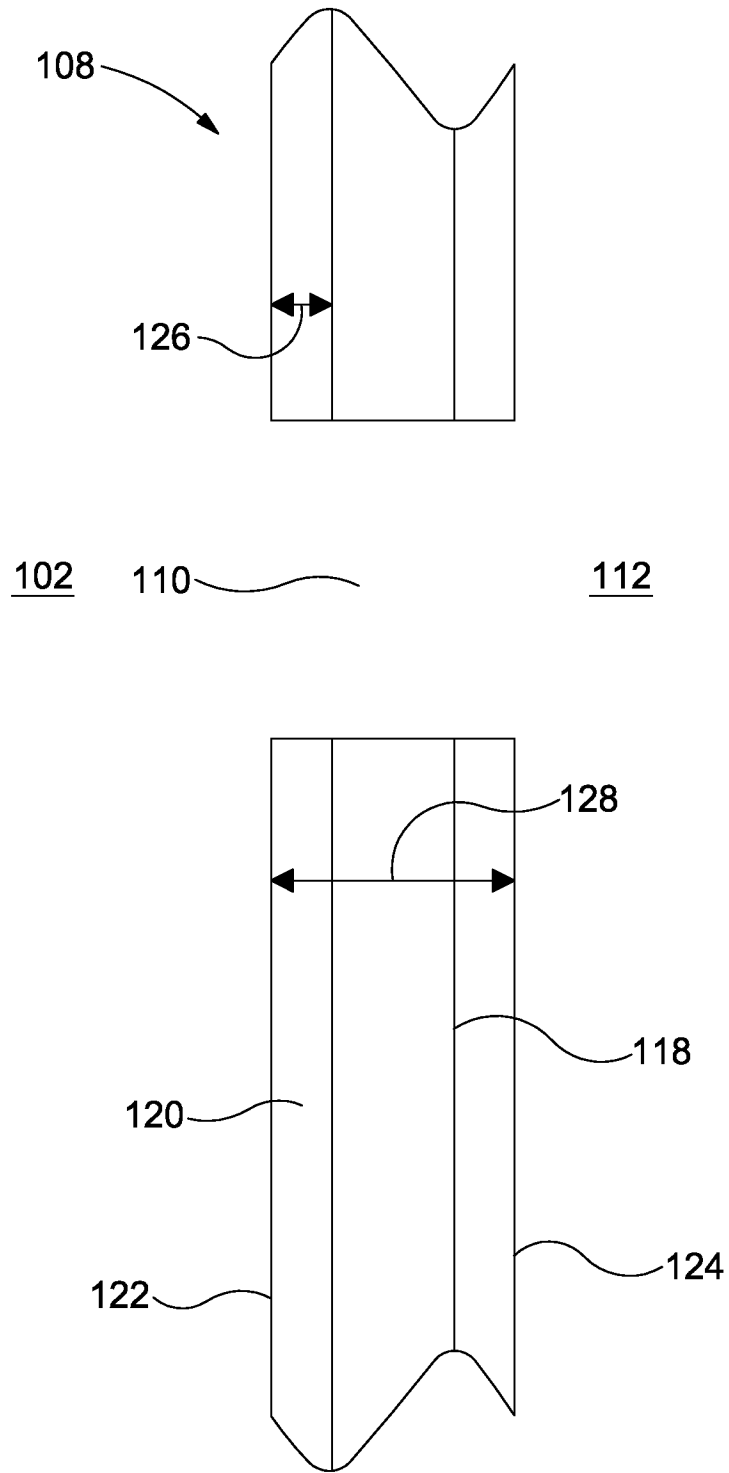


FIG. 2

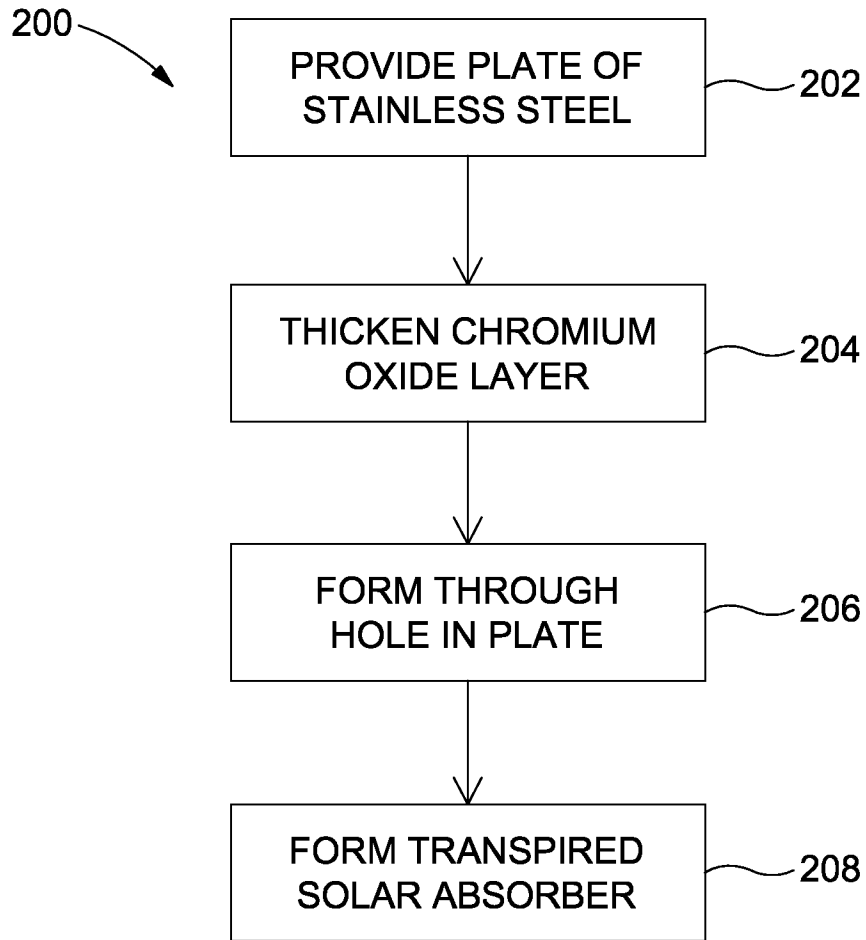


FIG. 3

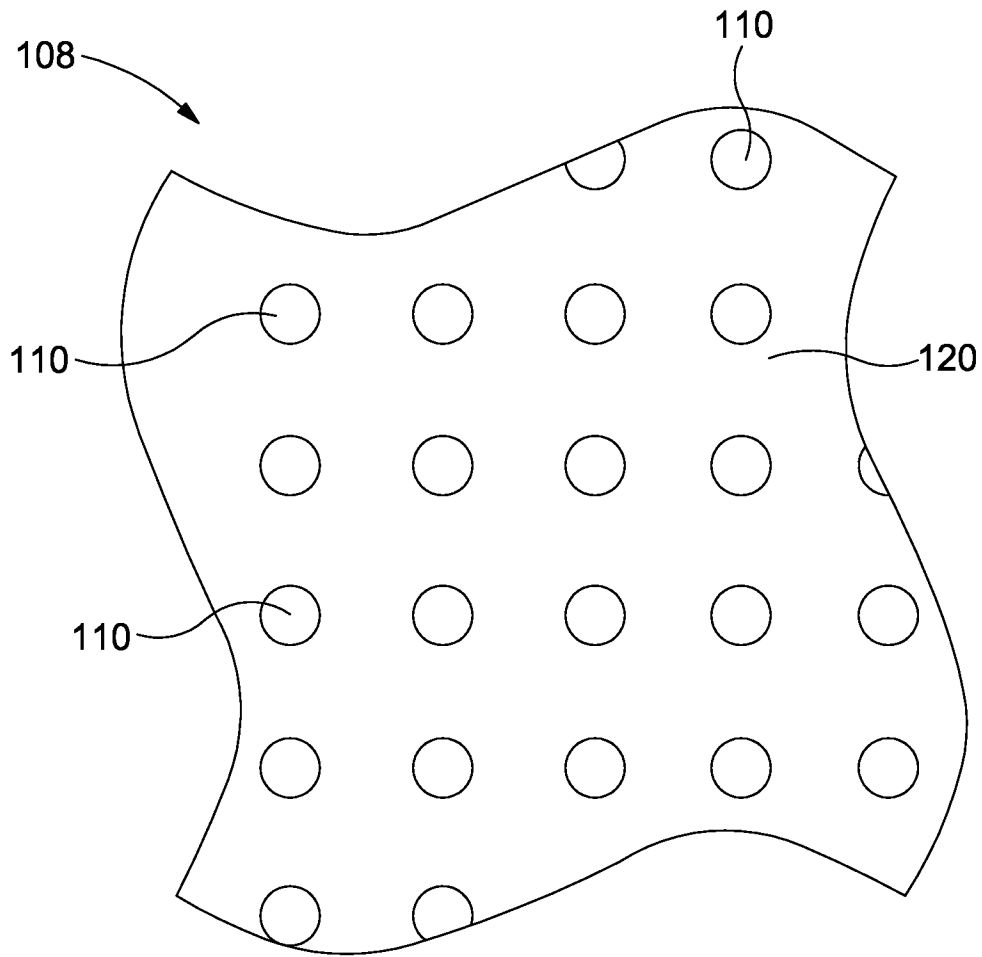


FIG. 4

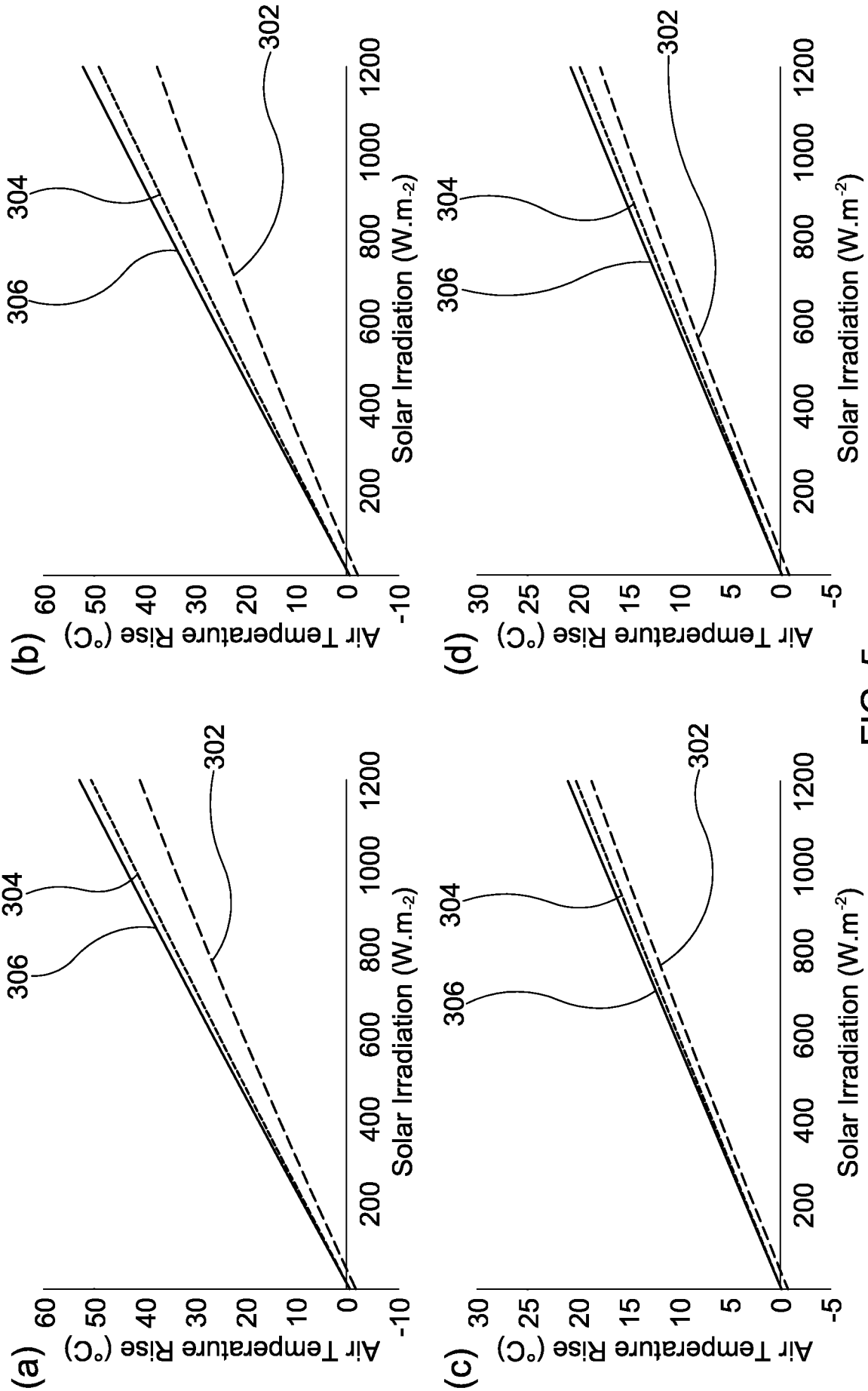


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2016/052109

A. CLASSIFICATION OF SUBJECT MATTER  
INV. F24J2/04 F24J2/28 F24J2/48  
ADD.  
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED  
Minimum documentation searched (classification system followed by classification symbols)  
F24J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 899 728 A (PETER ROLF W [CH] ET AL) 13 February 1990 (1990-02-13) column 3, line 18 - column 5, line 16; figures 1, 4a -----	1-21
Y	US 3 963 530 A (SMOLLETT THOMAS J ET AL) 15 June 1976 (1976-06-15) column 3, line 4 - column 4, line 68 -----	1-21
Y	DATABASE WPI Section Ch, Week 198335 Thomson Scientific, London, GB; Class J08, AN 1983-750318 XP002763700, -& JP 58 124161 A (MATSUSHITA ELEC IND CO LTD) 23 July 1983 (1983-07-23) abstract; figures 1-4 ----- -/--	1-21

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search  1 November 2016	Date of mailing of the international search report  11/11/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Beltzung, Francis

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