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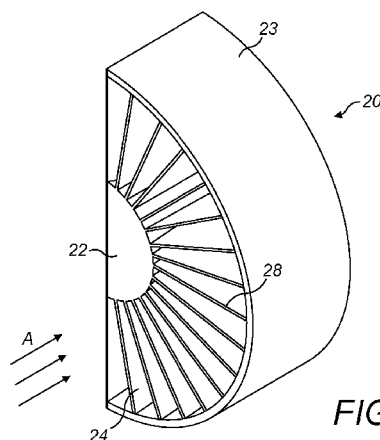


FIG. 3

(57) Abstract: A rotary desiccant wheel (20) for a passive ventilation system. The wheel has a surface coated with a desiccant for adsorbing moisture from air (A) flowing through the system. The wheel has a porosity Φ greater than or equal to approximately 65%. An existing passive ventilation system may be retrofitted with the rotary desiccant wheel. The passive ventilation system may be a wind tower.

ROTARY DESICCANT WHEEL

FIELD OF THE INVENTION

5 This invention relates to a rotary desiccant wheel for a passive ventilation system, a passive ventilation system, a building comprising a passive ventilation system and a method of retrofitting a passive ventilation system.

BACKGROUND OF THE INVENTION

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 In recent years, a need to reduce greenhouse gas emissions has become a major driving force in decreasing energy demand for the operation and maintenance of domestic and non-domestic buildings.

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 Passive ventilation is a method of ventilating buildings by manipulating natural forces around a building. Passive ventilation systems may be driven by driven by two forces: wind driven flow and the stack effect, as will be explained with reference to Figure 1.

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 Figure 1 shows an example of a building 2, such as a house. In Figure 1, the direction of wind flow is show by the arrows 4. Wind driven ventilation can effectively ventilate a building when surfaces of the building are subject to a driving flow. Pressure differences caused by the wind driven flow create areas of positive pressure (indicated at “A” in Figure 1) and negative pressure (indicated at “B” in Figure 1) around the building 2. Positive pressure can force air through any openings in the building fabric, whereas negative pressure
25 can cause suction forces, drawing air out of the building through the building fabric.

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 The stack effect is the natural process of air movement due to pressure differences caused by thermally stratified air. Warm air is less dense than cool air, this results in warm air rising in height and cool air flowing to fill the volume left unoccupied by the warm air. A difference between indoor and outdoor air temperature can provide a suitable driving force for ventilation to occur via the stack effect.

Wind towers are examples of passive ventilation systems, which can use the pressure differences created by wind driven flow and the stack effect to ventilate buildings. Based on traditional vernacular architectural features of Iranian Baud-Geer (also known as the Badgir wind tower), air can be channeled through a wind tower to ventilate a building. Though wind driven flow is predominantly the major driver in ventilation rates, the stack effect is also capable of providing the required flow rate through a wind tower.

The most common traditional wind towers are the Malkaf and the Badgir wind tower (for a description of these, see a journal article by Hughes BR, Calautit JK and Ghani SA entitled “The development of commercial wind towers for natural ventilation: a review”, published in Applied Energy 2012; 92:606–27).

Typically, a wind tower may be provided on the roof of a building, and includes an inlet for receiving a flow of air which is then directed to the interior of the building by a duct located within the tower itself. Typical heights of commercial wind towers are in the range 1-2 meters, with the inlet being provided at the top of the tower. Placing the inlet at this elevated position can allow the tower to receive a relatively clean flow of air and also allow the tower to receive a flow of air that is not inhibited by surrounding structures such as neighboring buildings.

Wind towers can provide a suitable level of ventilation to an occupied building and due to the action of introducing continuous amounts of fresh outdoor air to the indoor environment, remove pollutants that can build up in the air and cause ill health to occupants.

In humid climates, it is desirable to regulate the humidity of air in a building interior. For instance, air that has a lower relative humidity can more easily be conditioned to an appropriate temperature, thereby reducing the energy demand required by ventilation systems. In addition, relative humidity levels of 40-70% are commonly cited as an acceptable range for thermal comfort of occupants of the building.

In active heating, ventilation and air conditioning (HVAC) systems for buildings (which include fans for forcing the air through ducts and other components), rotary desiccant wheels have been used for transferring moisture to and from air flows within the system.

These rotary desiccant wheels are constructed of a honeycomb matrix, with a desiccant material being applied as a powder or gel to the material which makes up the honeycomb structure.

5 As the wheel rotates between two airstreams with varying relative humidity, moisture is adsorbed from the airstream with higher relative humidity to the matrix surface. This reduces the relative humidity downstream of the wheel. Rotation continues around to the second airstream which is at a higher temperature with lower relative humidity. The higher temperature is necessary for desorption of the moisture from the desiccant: this process is
10 known as the regeneration process, where the desiccant returns to its original state before adsorption. In active systems of this kind, a heater is provided to heat the second airstream to allow desorption to take place. The heater adds to the complexity and cost of the system and furthermore the power required to run the heater increases the energy requirements of the overall system.

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SUMMARY OF THE INVENTION

Aspects of the invention are set out in the accompanying independent and dependent claims. Combinations of features from the dependent claims may be combined with features of the independent claims as appropriate and not merely as explicitly set out in the claims.

According to an aspect of the invention, there is provided a rotary desiccant wheel for a passive ventilation system. The wheel has a surface coated with a desiccant for adsorbing moisture from air flowing through the system. The wheel has a porosity ϕ greater than or equal to approximately 65%.

A rotary desiccant wheel according to embodiments of this invention can be used in passive ventilation systems (systems which do not include fans for forcing the air through the system, and which may rely on wind driven flow and/or the stack effect as mentioned above). In particular, unlike the use of rotary desiccant wheels previously used in active ventilation systems, the high porosity of rotary desiccant wheels according to embodiments of this invention give rise to relatively low pressure drops across the wheel, so that flow rates in a passive ventilation system incorporating the wheel may remain acceptably high.

The rotary desiccant wheels having a honeycomb structure used in active systems ventilation systems have a porosity that is relatively low, whereby they produce a relatively large pressure drop across the wheel. In active systems of this kind, the fans that are used to force air through the system are able to overcome this pressure drop so that flow rates remain at an acceptable level. However, these kinds of rotary desiccant wheels having a honeycomb structure with a low porosity are generally not suitable for use in passive ventilation systems, since the pressure drop that they produce would give rise to flow rates that are too low.

Because rotary desiccant wheels according to embodiments of this invention give rise to relatively small pressure drops, the heat in warmer air that is exiting a building can be used in the regeneration of the desiccant. In contrast, the low porosity honeycomb structures used in active systems would not allow sufficient flow for warmer air to exit a building (e.g. by the Stack effect). Since heat from the warmer air exiting a building may be used for the regeneration process, a separate heater for enabling the regeneration may not be required.

In accordance with embodiments of this invention, the porosity of a rotary desiccant wheel in percentage terms may be defined as $100 \cdot (A_{\text{wheel}} - A_{\text{material}}) / A_{\text{wheel}}$, where A_{wheel} is the cross sectional area of the wheel as a whole that is presented to the airflow (if it is assumed that the cross sectional shape of the wheel is circular (which is not essential to embodiments of this invention), this is generally given by $\pi \cdot R_{\text{wheel}}^2$, where R_{wheel} is the radius of the wheel), and where A_{material} is the cross sectional area of the components of the wheel that are presented to the airflow, including any portion of the wheel providing the surface coated with a desiccant (e.g. the plates or concentric rings of the kind described herein), plus other portions such as an outer rim of the wheel or an axle of the wheel.

Various constructions are envisaged for a rotary desiccant wheel according to an embodiment of the invention. These constructions can each allow a wheel having a relatively high porosity to be produced.

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In one embodiment, the rotary desiccant wheel includes a plurality of plates coated with desiccant. Plates of this kind can be made relatively thin (whereby their impact on the porosity of the wheel can be reduced), while providing a relatively large surface area for receiving the desiccant, so that a large amount of desiccant can be used. The use of a large amount of desiccant in the wheel can increase the time until the desiccant requirement replenishment.

The plates can be aligned parallel to a direction of air flow within the system to allow air flowing through the system to pass freely over first and second opposite surfaces of the plates. In this way, a relatively large surface covered with the desiccant can be provided in a manner that provides a relatively small barrier to airflow. Thus, the rotary desiccant wheel can have a high porosity, so that the pressure drop across the wheel is correspondingly low.

The plates can be removably mounted on a body portion of the wheel, to allow convenient replacement and/or replenishment of the desiccant.

The plates can extend radially outward from a central axle of the wheel.

In one embodiment, the rotary desiccant wheel can include a plurality of concentric rings coated with the desiccant. Again, rings of this kind can be made relatively thin (whereby their impact on the porosity of the wheel can be reduced), while providing a relatively large surface area for receiving the desiccant, so that a large amount of desiccant can be used. The use of a large amount of desiccant in the wheel can increase the time until the desiccant requirement replenishment.

A central axis of the concentric rings can be aligned parallel to a direction of air flow within the system to allow air flowing through the system to pass over an inner surface and an outer surface of each ring. Again, in this way, a relatively large surface covered with the desiccant can be provided in a manner that provides a relatively small barrier to airflow.

In a one embodiment, the rotary desiccant wheel can have a porosity ϕ greater than or equal to approximately 66.1%. In a preferred embodiment, the wheel has a porosity ϕ greater than or equal to approximately 67%. In a particularly preferred embodiment, the wheel has a porosity ϕ greater than or equal to approximately 70%. In a further particularly preferred embodiment, the wheel has a porosity ϕ greater than or equal to approximately 73.5%. Simulations and experiments have shown that rotary desiccant wheels having porosities of this kind can avoid pressure drops of greater than 2 Pa across the wheel. In general, wheels having higher porosity produced smaller pressure drops, and this can be implemented using configurations including plates and/or concentric rings such as those mentioned above.

In one embodiment, the volume V_d of the desiccant covering the surface of the wheel is in the range $3.7 \times 10^{-4} \text{ m}^3 \leq V_d \leq 9.0 \times 10^{-4} \text{ m}^3$. A volume in this range can provide a sufficient amount of desiccant for the wheel so that the desiccant does not quickly become saturated. The large surface areas that can be provided by the configurations including plates and/or concentric rings such as those mentioned above can allow this volume of desiccant to be implemented in a manner that (despite the large volume) need not adversely affect the porosity of the wheel and restrict air flow.

The present rotary desiccant wheel comprises an active surface area of desiccant material that provides an optimised balance between humidity management (encompassing heat transfer between the desiccant wheel and air flow streams) on the one hand and

minimizing a pressure drop across the wheel on another. That is, the present wheel configuration is specifically adapted not to perturb or restrict air flow through the desiccant wheel due to '*skin friction*' effects resulting from the axial flow of air through the body of the wheel in contact with the axially extending surfaces of the wheel. This is, in contrast to earlier existing desiccant wheels that, whilst maximizing the active surface area of desiccant, are disadvantageous due to their large observed pressure drop which otherwise renders such wheels as unsuitable for passive and active/passive ventilations systems. Reference within this specification to active/passive systems refers to a ventilation system that is largely passive but may comprise air flow assistance including components such as fans, turbines, impellers and the like configured to assist air flow in the axial direction through the desiccant wheel. Preferably, the desiccant wheel as claimed herein is configured such that the quotient of: a total surface area of desiccant in an axial direction of the wheel/a total surface area of the wheel in the axial direction including and defined by a radially inward facing outer surface, a radially outward facing inner surface and the respective surfaces of the plates positioned between the inward and outward facing surfaces is in a range 0.5 to 1.0. Optionally, the quotient may be in a range 0.6 to 0.9, 0.7 to 0.9, 0.75 to 0.9.

The radially inward facing outer surface may comprise the inward facing surface of a cylindrical outer drum that defines an outer perimeter of the wheel. Additionally, the radially outward facing inner surface may comprise the outward facing surface of a sleeve, collar or drum that surrounds an axle on which the desiccant wheel is rotatably mounted. Naturally, such inner and outer drums do not need to be cylindrical and may comprise other shape profiles. The respective surfaces of the plates positioned between the inward and outward facing surfaces may be aligned in a circumferential direction (for example concentric plates) and/or the surfaces of the plates may extend in a radial direction between the inward and outward facing surface. The quotient as claimed herein relating to the total surface area of desiccant and the total surface area of the wheel (as defined above) is advantageous to achieve the desired humidity management (adsorption and desorption of moisture at the wheel) whilst minimizing as far as possible a pressure drop across the wheel.

The capability of the wheel to dehumidify air in a passive ventilation system is also an aspect of the subject invention. In particular, the volume of desiccant relative to the total free volume within the desiccant wheel (the free volume space through the desiccant wheel in the

axial direction) is a further aspect that is advantageous for passive and passive/active systems. This provides a minimizing of any pressure drop across the desiccant wheel as the air flows for example from an external environment of the building into the building interior via the desiccant wheel. In particular, and preferably the quotient of a total volume of desiccant covering at least one surface of the wheel/a total air sector volume, where the total air sector volume is the free volume of air between neighbouring plates multiplied by the number of spaces defined between the plates is 0.01 to 0.3. Preferably, the quotient may be 0.02 to 0.2, 0.03 to 0.18 or more preferably 0.04 to 0.15.

The total air sector volume may be interpreted as the free volume or space between respective surfaces extending in the axial direction through the desiccant wheel where such surfaces may include the surfaces of the plates and/or the surfaces of the radially inward facing outer surface and the radially outward facing inner surface of the outer and inner drums (referred to above).

According to another aspect of the invention, there is provided a rotary desiccant wheel for a passive ventilation system, wherein the wheel comprises a plurality of plates coated with a desiccant for adsorbing moisture from air flowing through the system.

According to a further aspect of the invention, there is provided a rotary desiccant wheel for a passive ventilation system, wherein the wheel comprises a plurality of concentric rings coated with a desiccant for adsorbing moisture from air flowing through the system.

According to another aspect of the invention, there is provided a passive ventilation system. The passive ventilation system includes a rotary desiccant wheel of the kind described above for adsorbing moisture from air flowing through the system.

Prior to this invention, there have been no workable examples of passive ventilation systems incorporating a rotary desiccant wheel. Accordingly, embodiments of this invention can allow humidity control to be implemented in a manner that does not require features such as fans for driving the air through the system and/or a heater to allow desorption of moisture from the wheel to take place.

In one embodiment, the rotary desiccant wheel can be configured to adsorb moisture from air flowing in a first direction in the system, and to transfer at least some of the moisture to air flowing in a second direction in the system. In this way, regeneration of the desiccant can take place. The air flowing in a second direction in the system can be routed to leave the system (e.g. vented to the exterior of a building incorporating the system), so that moisture that is desorbed from the desiccant also leaves the system.

In one embodiment, the rotary desiccant wheel can be operable to rotate so that each part of the surface coated with a desiccant is exposed to air flowing in the first direction during a first part of its rotation and exposed to air flowing in the second direction during a second part of its rotation. In some examples, a motor may be used to drive the rotation of the wheel. The motor may be solar powered.

The passive ventilation system may include a duct. The rotary desiccant wheel can be mounted in the duct.

In one embodiment, the duct can include a plurality of channels for separating air flowing in the first direction in the duct from air flowing in the second direction in the duct.

The passive ventilation system may be a wind tower for a building. The wind tower can include an opening for allowing air to enter and exit the tower. The wind tower can also include a duct for allowing air to flow between an interior of the building and the opening. The rotary desiccant wheel can be positioned in the wind tower for adsorbing moisture from air flowing from the opening of the wind tower to the interior of the building. For instance, the rotary desiccant wheel can be positioned in the wind tower to adsorb moisture from air flowing from the opening of the wind tower to the interior of the building, and to transfer at least some of the moisture to air flowing from the interior of the building to the opening of the wind tower.

It is envisaged that the passive ventilation system may take other forms, for instance it may comprise a vent passing through a wall or window of a building, e.g. to create a single sided or cross sided ventilation system. In one example, vents including a rotary desiccant wheel of the kind described herein may be located in the windows of an atrium in a building.

The vents may be provided in windows leading to the atrium at different floor levels of the building.

According to a further aspect of the invention, there is provided a building including a
5 passive ventilation system of the kind described above. For instance, where the passive ventilation system comprises a wind tower, the building may comprise a wind tower located on a roof or other exterior surface of the building.

According to another aspect of the invention, there is provided a method of
10 retrofitting a passive ventilation system. The method includes positioning a rotary desiccant wheel of the kind described above in the passive ventilation system to adsorb moisture from air flowing through the system.

Retrofitting an existing passive ventilation system with a rotary desiccant wheel of the
15 kind described above can allow existing systems to provide humidity control in manner that need not require complete replacement of the passive ventilation system.

Where the passive ventilation system includes a wind tower for a building, the wind tower including an opening for allowing air to enter and exit the tower, and a duct for
20 allowing air to flow between an interior of the building and the opening, the method can include positioning the rotary desiccant wheel in the wind tower, for adsorbing moisture from air flowing from the opening of the wind tower to the interior of the building.

According to a further aspect of the present invention there is provided a method of
25 passive ventilation of a building comprising: allowing an inward flow of air from an external region of a building into an interior of the building via a wind tower; allowing rotation of a desiccant wheel positioned within the wind tower; adsorbing moisture from the inward flow of air at the desiccant wheel; allowing an outward flow of air from the interior of the building through the wind tower to the external region of the building; allowing moisture
30 adsorbed at the desiccant wheel to transfer from the desiccant wheel to the outward flow of air through the wind tower; wherein the desiccant wheel comprises a surface coated with a desiccant for adsorbing the moisture from the inward flow of air flowing through the wind tower, the desiccant wheel having a porosity ϕ greater than or equal to approximately 65%.

Optionally, the method further comprises controlling the rotational speed of the desiccant wheel to be in the range 5 rpm to 30 rpm, 10 rpm to 20 rpm or more preferably 15 rpm to 20 rpm. Such rotational speeds, optionally in combination with the relative porosity, active surface area of desiccant in the axial direction and volume of desiccant in the axial direction provide the desired balance of humidity management versus pressure drop across the wheel. Humidity management encompasses a desired adsorption and desorption of moisture at the desiccant for a desired air temperature range, air flow speed and air flow volume within a passive or passive/active ventilation system.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be described hereinafter, by way of example only, with reference to the accompanying drawings in which like reference signs
5 relate to like elements and in which:

Figure 1 shows an example of wind flow in the vicinity of a building;

Figure 2 shows a section of a rotary desiccant wheel according to an embodiment of the invention;

10 Figure 3 shows a section of a rotary desiccant wheel according to an embodiment of the invention;

Figure 4 shows a part of a rotary desiccant wheel in accordance with an embodiment of the invention;

15 Figure 5 shows a plate coated with a desiccant, which can be used in a rotary desiccant wheel in accordance with an embodiment of the invention;

Figure 6 shows a rotary desiccant wheel in accordance with an embodiment of the invention;

Figure 7 shows a wind tower in accordance with an embodiment of the invention;

20 Figure 8 shows a building having a wind tower in accordance with another embodiment of the invention;

Figure 9 shows the arrangement of a duct having a plurality of channels in a wind tower in accordance with an embodiment of the invention;

Figure 10 is a cut-away view illustrating the operation of a wind tower in accordance with an embodiment of the invention;

25 Figure 11 shows the results of relative humidity measurements for demonstrating the operation of a rotary desiccant wheel according to an embodiment of the invention; and

Figure 12 shows the results of air temperature measurements for demonstrating the operation of a rotary desiccant wheel according to an embodiment of the invention;

30 Figure 13 is a graph of relative humidity change of an incoming air stream against external air temperature for two different desiccant wheel configurations;

Figure 14 is a further graph of relative humidity change of an outgoing air stream against external air temperature for two different desiccant wheel configurations;

Figure 15 is a further graph of relative humidity change of an incoming air stream against external air temperature for two different desiccant wheel configurations;

Figure 16 is a further graph relative of humidity change of an outgoing air stream against external air temperature for two different desiccant wheel configurations.

DETAILED DESCRIPTION

Embodiments of the present invention are described in the following with reference to the accompanying drawings.

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The embodiments of this invention can provide a rotary desiccant wheel for a passive ventilation system. The wheel has a surface that is coated with a desiccant for adsorbing moisture from air flowing through the system. The wheel has a porosity that is greater than or equal to approximately 65%. The relatively high porosity of the wheel presents a minimal barrier to airflow within a passive ventilation system incorporating the wheel. Embodiments of this invention can therefore provide humidity control in a manner that is compatible with passive ventilation systems, which do not include features such as fans for forcing air through the system. Instead, humidity control can be provided in a system that relies on forces such as wind driven flow and/or the stack effect.

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Moreover, because the pressure drop across a rotary desiccant wheel of the kind described herein is relatively low, the heat needed to regenerate the desiccant of the wheel to prevent it becoming saturated can be provided by warmer air exiting a building through the passive ventilation system. Accordingly, it need not be necessary to provide a separate heater for regeneration purposes, which can reduce the power consumption associated with ventilating a building. Note that conventional rotary desiccant wheels based on a honeycomb design cannot benefit from this effect, since the pressure drop across any such wheel is too great to allow significant flow through the wheel in the absence of a fan for forcing air through the system. As previously mentioned, although it is known to regenerate a rotary desiccant wheel having the honeycomb design in an active ventilation system, typically a separate heater is provided to heat the air for these purposes.

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Figure 2 shows a section (a half) of a rotary desiccant wheel 20 according to a first embodiment of this invention. The rotary desiccant wheel 20 includes a central axle 22. The rotary desiccant wheel 20 also includes a rim 23. The rotary desiccant wheel 20 further includes one or more spokes 26 which provide structural strength.

30

The rotary desiccant wheel 20 further includes a plurality of concentric rings 30. The concentric rings 30 are arranged coaxially with respect to the axle 22. The concentric rings 30 can be mounted on the spokes 26. As shown in Figure 2, the concentric rings 30 may be evenly spaced, although it is also envisaged that the distance between adjacent rings may vary so that some of the concentric rings 30 are spaced further away from their nearest neighbours than others. Each of the concentric rings 30 has an inner surface (which faces towards the axle 22) and an outer surface (which faces away from the axle 22). The inner surface and/or outer surface of at least some (and preferably all) of the concentric rings 30 is coated with a desiccant. In this embodiment, air flowing through the passive ventilation system can flow in between the concentric rings 30 of the rotary desiccant wheel 20 to pass through the wheel 20. As the air flows in between the concentric rings 30, it comes into contact with the desiccant located on the surfaces of the concentric rings 30. In this way, moisture can be adsorbed by the desiccant. Thus, the rotary desiccant wheel 20 can remove moisture from a flow of air in a passive ventilation system.

As noted above, a central axis of the concentric rings 30 can coincide with the axis of the axle 22, so that air that is incident upon the rotary desiccant wheel 20 (represented by the arrows labelled "A" in Figure 2) can flow freely through the spaces 24 between the concentric rings 30. In this way, the concentric rings 30 can present the least amount of cross-sectional area to the incident flow of air, reducing the effective porosity of the wheel 20. As will be described in more detail below, a regeneration process can also allow moisture to be desorbed from the desiccant.

Figure 3 shows a section (a half) of a rotary desiccant wheel 20 according to another example embodiment of this invention. The rotary desiccant wheel 20 in this embodiment also includes an axle 22 and a rim 23. In this embodiment, the rotary desiccant wheel 20 includes a plurality of plates 28, which are coated with a desiccant. The plates 28 can be aligned parallel to a direction of the airflow incident upon the rotary desiccant wheel 20 (e.g. as represented by the arrows labelled "A" in Figure 3) so as to present a minimum cross-section to the incident air and to maximise the porosity of the wheel 20.

As shown in Figure 3, in this embodiment, the plates 28 are arranged to fan radially outward from the axle 22 to meet the rim 23. As with the concentric rings 30 noted above in

respect of Figure 2, the plates 28 can be made relatively thin, while providing a relatively large surface area for the provision of a desiccant. Again, air flowing through the desiccant wheel 20 can flow in the spaces 24 between the plates 28, where it may come into contact with desiccant provided on at least some of the surfaces of the plates 28, whereby moisture
5 can be adsorbed from the air flow. As will be described in more detail below, a regeneration process can also allow moisture to be desorbed from the desiccant.

The overall size of a rotary desiccant wheel according to an embodiment of this invention can be chosen to match the physical size of features of the passive ventilation
10 system in which it is provided. For instance, the diameter of a rotary desiccant wheel of the kind shown in Figures 2 and 3 can be chosen so that it fits in a duct or other feature of a passive ventilation system. As will be described below, it is envisaged that a rotary desiccant wheel of the kind herein can be incorporated in the base of a wind tower. In such examples, the diameter of the wheel can be chosen to fit within the cross-sectional size of the base.

Figure 4 shows a section 42 of a rotary desiccant wheel in accordance with another embodiment of this invention. Four sections 42 of the kind shown in Figure 4 can be joined together to form a wheel of the kind shown in Figure 3, for example. The section 42 includes a wall 44 that forms the rim 23 of the wheel and that also has an inner surface 52 that defines
20 a number of slots 48, 50 for receiving plates 28 of the kind shown in Figure 5. The plates can be slotted into the slots 48, 50 conveniently to allow their installation and removal for maintenance or replacement. The slots can be positioned such that, when the plates 28 are placed in the slots, they fan out from the axle of the wheel 20 to meet the rim 23 as shown in Figure 3. Note that the plates may be arranged in other ways, and need not fan out radially as
25 described here.

The plates 22 shown in Figure 5 each include a first surface and a second surface. The first surface is on an opposite side of the plate 28 to the section surface. The first surface and/or the second surface may be coated with a desiccant 38 as noted above.

The desiccant used for coating the surfaces of a rotary desiccant wheel of the kind described herein may, for example, comprise silica in the form of a powdered gel. The average particle size of the powder may be around 1mm (diameter). The desiccant may be

non-indicating silica may be type A silica. The desiccant may be non-indicating silica gel. The silica gel may conform to British Standard BS7554:1992. Silica of this kind can adsorb up to 40% of its own weight in moisture. This kind of silica was used in the experiments described below in relation to Figures 11 and 12.

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As the desiccant adsorbs moisture from the air flowing in the passive ventilation system, it may, over time, become saturated. When the desiccant is saturated, it can be replaced. For instance the plates may be removed from the wheel and replaced with plates 28 coated with fresh desiccant. The regeneration process described in more detail below can
10 lengthen the amount of time that the saturation condition takes to occur. In some cases, the time to saturation may exceed the lifetime of the wheel itself, so that in principle the desiccant may never need to be replenished.

The amount of time that it takes for the silica to become saturated can be lengthened
15 by providing a larger volume of desiccant. In particular, it has been determined that, irrespective of the overall size and configuration of the wheel, the volume V_d of the desiccant covering the surface of the wheel can be in the range $3.7 \times 10^{-4} \text{ m}^3 \leq V_d \leq 9.0 \times 10^{-4} \text{ m}^3$. Note that a further benefit of a desiccant wheel having a configuration of the kind shown in Figure 2 or Figure 3 is that a sufficient amount of surface area can be provided to support this
20 relatively large volume of desiccant while presenting a relatively small cross section to the incident air flow owing to the high aspect ratio of the concentric rings or plates. Provision of this volume of desiccant would not be possible in a prior rotary desiccant wheel of the honeycomb type, because the dense packing of the honeycomb structure would not provide sufficient room for it.

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In some embodiments, the rotary desiccant wheel 20 can be provided in a housing 60 of the kind shown in Figure 6. The housing 60 can include a number of side walls for protecting the rotary desiccant wheel 20. The side walls can include openings for allowing air to enter the housing to flow through the wheel 20. The housing 60 can be mounted within
30 for example, a duct of a passive ventilation system having a rectangular (e.g. square) cross-section. In one embodiment, the housing can be mounted in a base of a wind tower as explained below. In some embodiments, a member 55 may extend across a face of the rotary

desiccant wheel 20 to provide a rotation point 54 to which the axle 22 of the rotary desiccant wheel 20 can be connected and about which the rotary desiccant wheel 20 can rotate.

As will be explained in more detail below, in order to allow regeneration of the desiccant provided on the surface of the rotary desiccant wheel 20, the wheel 20 can be configured to rotate so that it comes into contact with two separate air streams in a passive ventilation system. This can allow moisture adsorbed from a first of the air streams during a first part of a rotation of the wheel to be desorbed into air in a second of the air streams. The rotary desiccant wheel 20 may accordingly be provided with features such as a motor (for instance an electrical motor, which may be solar powered) to enable this rotation. The speed of rotation can be chosen to optimise the regeneration process.

It is envisaged that the rotary desiccant wheel described herein can be incorporated in to a number of different kinds of passive ventilation systems. In the following, the operation of a rotary desiccant wheel 20 within a passive ventilation system comprising a wind tower will be described. The exterior of the example wind tower 100 is shown in Figure 7.

The wind tower 100 may be mounted on a surface such as a roof of a building (e.g. a house, office or warehouse). The wind tower 100 includes a base 102. The wind tower 100 has a substantially square cross-section although other shapes are envisaged. The wind tower 100 has a roof section 104 for sealing off an upper part of the wind tower to prevent rain or other materials from entering the top of the tower 100. The wind tower 100 further includes an opening 106. The opening 106 has four parts, each part of the opening being provided on a respective side of the wind tower 100. The opening 106 can, in some embodiments, be provided with louvres 108, again to prevent the ingress of rain, dust or other unwanted materials. Air can exit and/or enter the wind tower 100 through the opening 106. Generally, air enters the wind tower 100 through the part(s) of the opening 106 that are presented to an incoming airflow (the windward side(s)), whereas air exits the opening 106 through the part(s) of the opening 106 that are on the leeward side(s) of the tower 100.

Figure 8 shows a wind tower 100 of the kind shown in Figure 7 located on the roof of a building 110. In the example of Figure 8, the prevailing direction of wind is shown by the arrow labelled A. Air incident upon the windward side of the tower 100 enters the tower 100

through the part(s) of the opening 106 that face the incoming wind and flows down through the wind tower 100 into the interior 112 of the building as indicated by the arrow labelled B. The tower 100 has a rotary desiccant wheel 20 located in its base 102. Air entering the interior 112 of the building 110 through the tower 100 flows through the wheel 20. As the air
5 flows through the wheel, 20, moisture can be removed from the air, so the air reaching the interior 112 may have a lower relative humidity than the air outside the building 110.

Negative pressure on the leeward side of the wind tower 100 can draw air up through the wind tower 100 as shown by the arrow labelled C in Figure 8, to allow stale air 112 to
10 exit the building 110. This air may also pass through the rotary desiccant wheel 20 located in the base 102 before exiting the wind tower 100 through the leeward part(s) of the opening as shown by the arrow labelled D.

The stack effect may also contribute to the air flow within the wind tower 100, such
15 that warm air may rise to the top of the building interior 112 and exit the wind tower 100 as shown by the arrows labelled C and D. Conversely, cooler air at the exterior of the building 110 can enter the building interior 112 through the wind tower 100 as shown by the arrows labelled by A and B. Air entering and exiting the building 110 due to the stack effect also, of course, passes through the rotary desiccant wheel 20. A rotary desiccant wheel 20 located in
20 a passive ventilation system, such as at the base 102 of the wind tower 100 can provide humidity control of air entering the interior 112 of the building 110 (i.e. the air indicated by the arrow labelled B). Air exiting the interior 112 of the building 110 as shown by the arrows labelled C and D can be used for regeneration of the desiccant of the rotary desiccant wheel 20.

Figure 9 shows the cross-sectional configuration of the wind tower 100 in this embodiment. The wind tower 100 includes a side wall 134. The opening 106 can include four parts 106A, 106B, 106C, 106D. Each part 106A, 106B, 106C, 106D of the opening 106 is, in this embodiment, provided in a respective side of the wind tower 100. The interior of
30 the wind tower 100 is provided with a partition 70 which is X-shaped in order to divide the interior of the wind tower 100 (i.e. the duct 80) into a plurality of channels 132A, 132B, 132C, 132D. Each duct 132A, 132B, 132C, 132D is in fluid communication with a respective one of the parts 106A, 106B, 106C, 106D of the opening 106. It will be

appreciated that air can enter and/or exit the wind tower 100 by entering through any one of the opening parts 106A, 106B, 106C, 106D as noted above and by passing through a respective one of the channels 132A, 132B, 132C, 132D. It will also be appreciated that air can exit the wind tower 100 in a similar manner through any one of the channels 132A, 132B, 132C, 132D of the duct 80 and its respective part 106A, 106B, 106C, 106D of the opening 106. The direction of wind flow outside the building can determine the direction of flow within the channels of the duct 80 as explained above.

The rotary desiccant wheel 20 is visible in the cross-sectional view of Figure 9. Figure 9 also shows the housing 60 described above in relation to Figure 6. Note that in the configuration as shown in Figure 9, any given part of the rotary desiccant wheel 20 is presented to each of the channels 132A, 132B, 132C, 132D during a complete rotation of the wheel 20, so that any given surface covered with desiccant in the rotary desiccant wheel 20 would generally, during a complete rotation of the wheel 20 be presented to air that is either entering the building 110 through one or more of the channels 132A, 132B, 132C, 132D and also to air that is exiting the building 110 through one or more other channels 132A, 132B, 132C, 132D. This configuration can thus support regeneration of the desiccant of the rotary desiccant wheel 20 as will be described in more detail below in relation to Figure 10.

Figure 10 shows a cut away view of the wind tower 100 described above. The channels 132A and 132B are visible in this view, as are the parts 106A and 106B of the opening 106 with which the channels 132A and 132B are in fluid communication. Figure 10 also shows the roof section 104, louvres 108, the partition 70, the base 102 and the position of the rotary desiccant wheel 20 in the base 102. In some embodiments, guides 116 may be used to guide the air flowing along the channels of the wind tower 100. The guides may, as shown in Figure 10, be positioned between the opening 106 and the rotary desiccant wheel 20, e.g. adjacent the rotary desiccant wheel 20.

Air entering the wind tower 100 through the part 106A of the opening is denoted by the arrows labelled "A" in Figure 10. This flow of air flows down through the channel 132A of the wind tower 100 as shown by the arrows labelled B, past the guides 116, and through the rotary desiccant wheel 20. The air that passes through the rotary desiccant wheel (indicated by the arrows labelled "C" in Figure 10) may have a lower relative humidity owing

to the adsorption of moisture from the air by the desiccant of the wheel 20 as described above. This air may subsequently enter the interior of the building incorporating the passive ventilation system. Air may also exit the interior of the building through the wind tower 100, as denoted by the arrows labelled “D” in Figure 10. This air passes through the rotary desiccant wheel 20, up through the channel 132B, and can exit the wind tower 100 through the part 106B of the opening. The air flows described here in relation to Figure 10 may be wind driven flows and/or may arise from the stack effect.

The air exiting the interior of the building through the wind tower shown in Figure 10 may be used to regenerate the desiccant of the rotary desiccant wheel 20. In particular, moisture adsorbed by the desiccant of the rotary desiccant wheel 20 may be desorbed to the air flowing out through the tower 100 as indicated by the arrows labelled “D”, “E” and “F”. To implement this, in accordance with an embodiment of the invention, the wheel 20 may be operable to rotate within the base 102 of the tower 100 so that each part of the surface of the wheel 20 (e.g. each plate of the kind described above, or each section of each concentric ring) coated with a desiccant is exposed to the air flow at “B” (i.e. air entering the tower 100) during a first part of its rotation and is subsequently exposed to the air flow at “D” during a second part of its rotation. Since the air flow at “D”, which originates from the interior of the building, is typically warmer (e.g. because of the stack effect) and less humid (e.g. because moisture was removed from the air entering the building by the action of the rotary desiccant wheel 20), it is able to allow moisture adsorbed by the desiccant of the wheel 20 to be desorbed into the exiting flow of air.

Accordingly, during each rotation, each part of the wheel is exposed to air flowing in a first direction in the tower 100 for adsorbing moisture from that flow, and is exposed to air flowing in a second direction in the tower 100 for desorbing moisture to that flow. The air exiting the tower 100 can carry away the moisture desorbed by the desiccant of the wheel 20 so that it leaves the system. In this way, the amount of time that the wheel 20 can operate for before the desiccant becomes saturated may be lengthened. Typical time periods before saturation occurs may be at least around 1 year, and potentially may be much longer. In some cases, the time to saturation may exceed the lifetime of the wheel itself, so that in principle the desiccant may never need to be replenished.

Note that although the regeneration process has been described in the context of a wind tower, it is envisaged that regeneration of this kind may be implemented in any passive ventilation system including a plurality of air flows, where moisture is adsorbed from one of the air flows and desorbed into another of the air flows.

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CFD calculations have been performed to determine the porosity values of rotary desiccant wheels of the kind described herein that may be used to control humidity in a passive ventilation system. The parameters of these wheels is discussed below and set out further in Table 1.

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The diameter of the wheels studied in the CFD calculations, including the outer rim, was 300mm in each case (whereby the total area of the wheel $A_{\text{wheel}} = 70686\text{mm}^2$). In each case, the rim of the wheel was 8mm thick (so that the area of the rim itself was $= 70686 - 63347 = 7339\text{mm}^2$). In each case, the axle of the wheel had a diameter of 96mm (whereby the area of the axle was 7238mm^2). In the case of the wheels having concentric circles, four spokes (such as the spokes 26 in Figure 2) were provided, for supporting the concentric circles. These spokes had a total area of 376mm^2 . Since spokes of this kind may also be included in wheels of the kind shown in Figure 3 (i.e. to add structural strength), the area of four such spokes was also included in the calculations for the wheels having radial blades.

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Accordingly, each wheel had features forming a cross sectional area of 14953mm^2 , not including the features of the concentric rings or blades. Table 1 lists the configuration and additional area added by the concentric rings or blades of each wheel. Table 1 also lists the total material area of the wheel A_{material} including the area of the concentric rings or blades, plus that of the rim, axle and spokes. Table 1 further lists the porosity of each wheel, calculated using $\phi = 100 \cdot (A_{\text{wheel}} - A_{\text{material}}) / A_{\text{wheel}}$. Finally, Table 1 shows the calculated pressure before the wheel, after the wheel and the pressure drop across each wheel.

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Wheel type	Wheel Configuration	Additional area from wheel configuration (mm ²)	A _{material} (mm ²)	Porosity	Pressure (Pa): Before Wheel/After Wheel/Drop
Concentric Circles	Thickness of concentric rings: 5mm; radial width of spaces between rings: 10mm	17342	32295	54.3%	2.83/ -0.266/ 3.10
Concentric Circles	Thickness of concentric rings: 3mm; radial width of spaces between rings: 10mm	12073	27026	61.8%	2.16/ -0.226/ 2.39
Concentric Circles	Thickness of concentric rings: 2mm; radial width of spaces between rings: 10mm	8357	23310	67.0%	1.698/ -0.221/ 1.92
Concentric Circles	Thickness of concentric rings: 2mm; radial width of spaces between rings: 15mm	5781	20734	70.7%	1.268/ -0.244/ 1.51
Radial Blades	Number of plates: 36 Thickness of plates: 5mm	16920	31873	54.9%	2.563/ -0.438/ 3.00
Radial Blades	Number of plates: 56 Thickness of plates: 3mm	15792	30745	56.5%	3.300/ -0.355/ 3.66
Radial Blades	Number of plates: 32 Thickness of plates: 3mm	9024	23977	66.1%	1.670/ -0.403/ 2.07
Radial Blades	Number of plates: 20 Thickness of plates: 2mm	3760	18713	73.5%	1.153/ -0.305/ 1.46

Table 1: CFD calculations of Porosity vs. Pressure Drop for Rotary Desiccant Wheels according to Embodiments of this Invention.

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From Table 1, it can be seen that the wheels with concentric circles of thickness 2mm (having porosity values of 67% and 70%) and the wheels with 32x3mm plates (having porosity value 66.1%) and 20x2mm plates (having porosity value 73.5%) each achieve a pressure drop of around 2 Pa or lower. A pressure drop of around 2 Pa or less is considered to be suitable for use in a passive ventilation system, because it is generally recognised that a pressure drop of more than around 2 Pa would block air flowing through the system (e.g.

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wind tower). Accordingly, it has been determined that a rotary desiccant wheel of the kind described herein, having a porosity of around 65% or higher, can allow humidity control to be implemented in a passive ventilation system in a manner that retains airflow through the system at an acceptable level.

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In order to simulate the rotary desiccant wheel in operational conditions, experimental testing has been conducted on a completed rotary desiccant wheel which was subjected to two independent cross-flow airstreams with different conditions. The inlet air flow represents air flowing in a first direction in a passive ventilation system (e.g. the air entering a wind tower of the kind described above), while the process air flow represents air flowing in a second direction in the passive ventilation system (e.g. the air exiting a wind tower of the kind described above). The velocity of the inlet air was 0.5ms^{-1} . The temperature of the inlet air was 26°C . A humidity generator was used to set the humidity of the air flows. The relative humidity (rH) of the inlet air was in the range 41-93%. The velocity of the process air was 0.5ms^{-1} . The temperature of the process air was 47°C . The relative humidity (rH) of the process air was 7%. The wheel was rotated at 1.5-2 rpm.

The wheel used in the experiment was of the kind shown in Figure 3. The wheel had 32 plates covered with silica gel. The diameter of the wheel was 300mm and the depth of the wheel was 100mm, the porosity of the wheel was 66.1%. The diameter of the central shaft was 96mm. The thickness of the outer rim was 8mm. The plate dimensions were 3x94x100mm.

Relative humidity and temperature were recorded at four separate locations each second for ten minutes to give a detailed view of the conditions in the two airstreams. Data was recorded 150mm before and after the rotary desiccant wheel in the inlet air channel and 150mm before and after the rotary desiccant wheel in the process air channel. For the first minute of testing the humidity generator was not directed down the inlet air channel in order for a clear differentiation to be seen between active adsorption and standard operation. The wheel was rotated continually for the entire ten minutes.

The measurements taken in the experiment are shown in Table 2, and are also plotted in Figures 11 and 12 (see Table 2 also for the Figure 11 and 12 reference numeral for each

data set). The measurements taken by the relative humidity and temperature probes were averaged for each minute of the duration of the experiment.

	Inlet Air Channel				Process Air Channel			
	Before Wheel		After Wheel		Before Wheel		After Wheel	
Fig. and ref. number	Fig. 11; 152	Fig. 12; 162	Fig. 11; 154	Fig. 12; 164	Fig. 11; 156	Fig. 12; 166	Fig. 11; 158	Fig. 12; 168
Time (s)	Humidity [%rH]	Temp. [°C]	Humidity [%rH]	Temp. [°C]	Humidity [%rH]	Temp. [°C]	Humidity [%rH]	Temp. [°C]
0	41.70	26.70	26.20	28.10	7.10	47.90	10.20	44.60
60	42.33	26.57	26.05	28.09	7.04	47.98	10.26	44.14
120	42.02	26.00	26.51	28.66	6.80	48.79	10.64	44.37
180	79.77	23.48	29.45	29.20	6.70	49.03	10.83	44.28
240	81.78	22.45	29.15	29.65	6.70	48.91	10.83	44.32
300	82.47	21.92	28.49	29.83	6.90	48.38	11.21	43.82
360	83.43	21.37	27.84	30.00	7.10	47.88	11.26	43.46
420	89.13	20.80	27.65	30.11	7.20	47.70	11.51	43.35
480	93.35	20.40	27.82	30.00	7.10	48.00	11.66	43.59
540	93.54	20.33	28.71	30.09	6.81	48.83	10.71	44.69
600	91.28	20.11	27.46	30.37	6.60	49.68	10.23	45.29

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Table 2: Summary of Humidity and Temperature Measurements.

A number of conclusions can be drawn from the data about the ability of the rotary desiccant wheel to transfer moisture from one channel to the other. For the first two minutes of activity, a decrease of approximately 16% relative humidity in the inlet air channel can be seen, correlating to a 2°C increase in temperature. This gives a baseline level of moisture

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transport. For the same time period, an average relative humidity of 7% before the wheel in the process air channel; increases to 10% after the wheel, reducing the temperature by 3°C.

As the relative humidity before the wheel increases beyond 180 seconds, due to the humidifier being directed down the inlet air channel, the moisture removal by the desiccant material increases significantly. Moisture removal peaks at 65.53% at 480 seconds, corresponding to a 9.6°C increase in air temperature. However, the temperature increase continues to rise after the maximum moisture transfer.

The change in relative humidity in the process air channel reaches a peak value of 4.56%, also at 480 seconds. This suggests that as the maximum adsorption levels are reached by the silica gel granules, the maximum desorption rate is also experienced. However, the greatest air temperature change between the two measurement locations is at 180 seconds, the time when the effect of the humidifier can be most clearly seen.

The graphs in Figures 11 and 12 indicate that the measurements of the process air data closely match trends whereas the measurements of the inlet air data do not. This suggests that the inlet air is more susceptible to changes in conditions compared to the process air.

Moisture removal from an airstream has been noted as high as 65% for a prolonged time. Despite a relatively low desorption of 4%, it has been shown that the desiccant material is capable of continually removing moisture from air, outputting air at a consistent 30% relative humidity regardless of the relative humidity value before the wheel. This has significant applications, particularly in the area of passive ventilation where air velocity is lower than that of forced ventilation. The structure of a rotary desiccant wheel of the kind described herein, having a low porosity, can allow a low velocity air flow to pass through without high pressure drop.

Accordingly, there has been described a rotary desiccant wheel for a passive ventilation system. The wheel has a surface coated with a desiccant for adsorbing moisture from air flowing through the system. The wheel has a porosity ϕ greater than or equal to approximately 65%. An existing passive ventilation system may be retrofitted with the rotary desiccant wheel. The passive ventilation system may be a wind tower.

The previous experiments discussed above confirm that the present wheel configuration reduces the pressure drop commonly seen in existing rotary desiccant wheels whilst being capable of dehumidification of an airstream. Whilst the aim of the initial experiments was to determine if the present design was capable of dehumidifying an airstream without impeding the air flow through it, the goal of some of the experiments detailed below was to further optimise the configuration under different operating conditions with the aim of reducing the regeneration temperature whilst maintaining the relative humidity reduction.

As noted, the regeneration temperature is the temperature at which the desiccant of the radial plates is capable of appreciable moisture exchange, i.e., adsorption and desorption, where the water molecules adsorbed to the pore surface of the silica gel from the inflowing airstream and are then removed to the outflowing air stream. For typical rotary desiccant wheels, this temperature is generally high, being 60°C and above. In order for systems to provide this temperature, as noted previously, electric heaters are employed which increase the energy costs of the system. Naturally, by reducing the regeneration temperature of a system, considerable energy savings are possible. Furthermore, the present experiments confirm the potential to further improve the wheel configuration to achieve an even smaller pressure drop of the previous experiments. The following experiments were based on 32 and 20 3mm thick radial plates (1mm Perspex sheets coated with 2mm of silica gel particles). The increased airflow 'openings' (free flow volume between the plates) of the rotary desiccant wheel should lead to a lower pressure drop.

The dehumidification capabilities of two wheel configurations were tested under the same conditions in order to assess the effect of the number of plates on dehumidification and pressure drop performance. The relative humidity and air temperature were measured before and after the wheel in two air streams that were subject to different conditions. The incoming air refers to the air stream at high relative humidity and lower air temperature, as before corresponding to an air source from an outdoor environment to be introduced into a building. The relative humidity of this air was set as close to 100% as possible on the day depending on local climatic conditions, although the air temperature could not be controlled exactly and so was a product of local climatic conditions and the high relative humidity. The outgoing air

refers to the air stream at low relative humidity and higher air temperature, corresponding to the exhaust air leaving a building. The external air temperature refers to the regeneration temperature that is used for regeneration of the desiccant (silica gel) by desorption. Four different external air temperatures were measured, all lower than the commonly used regeneration temperatures. This helped to determine the effectiveness of the present wheel configuration at lower regeneration temperatures and to find the optimal temperature, balancing dehumidification and energy use.

Table 3 shows the changes to relative humidity before and after the rotary desiccant wheel in the incoming and outgoing air streams for both the 20 and 32 plate configurations. A positive value of relative humidity change relates to a decrease in relative humidity and a negative value of relative humidity change relates to an increase in relative humidity.

External Air Temperature (°C)	20 Plates		32 Plates	
	Incoming Air Humidity Change	Outgoing Air Humidity Change	Incoming Air Humidity Change	Outgoing Air Humidity Change
25	13.66	-7.90	54.77	-5.75
30	29.96	-10.36	59.38	-7.74
35	35.82	-11.61	62.25	-7.49
40	2.55	-9.27	67.01	-6.93

Table 3 – Experimental Results showing Relative Humidity Change in the Incoming and Outgoing Air Channels for 20 and 32 radial plates.

The most obvious conclusions that can be drawn from the data are that for all cases, as the external air temperature increases, the humidity change increases. This was expected based on what was previously known and observed. Similarly, the change in relative humidity of the incoming air streams is greater for the 32 plate configuration than the 20 plate configuration as there are more silica gel particles for adsorption. It is interesting to note that the change in relative humidity in the outgoing air stream is higher in the 20 plate

configuration than the 32 plate configuration, this is likely due to the lower concentration of silica gel particles to which the external air temperature is affecting.

It is worth noting that the experiment at an external air temperature of 40°C for the 20 plate configuration did not operate as expected. The significantly lower change in relative humidity of the incoming air appears to be an anomalous result. It is expected that the change in relative humidity should be 45-55%, this can be more clearly seen in Figure 13 where the 32 plate wheel is data 170 having linear fit line 171 and the 20 plate wheel is data 172 having linear fit line 173. As a consequence of the low change in relative humidity of the incoming air, the change in relative humidity of the outgoing air is also lower than expected.

The trends of the data can be seen in Figures 13 and 14, in that as the external air temperature increases, the change in relative humidity for both the incoming and outgoing air streams increases. The rate at which the dehumidification effect increases for the 20 plate configuration compared to the 32 plate configuration is significant. This shows the potential for greater control of dehumidification using 20 plates compared to 32 plates where the dehumidification does not change by as significant a degree. Referring to figure 14, the 32 plate wheel is data 174 having linear fit 175 and the 20 plate wheel is data 176 having linear fit 177. The increased change in relative humidity of the outgoing air stream as shown in Figure 14 for the 20 plate configuration could provide evidence for increased longevity of the system as most water molecules are removed from the silica gel resulting in a slower saturation of the particles.

The regeneration potential of the silica gel particles was also tested. In particular particles were tested that had been in storage for a substantial amount of time and hence were to some extent moisture saturated. The relative humidity of the incoming air stream was not increased above the local climatic conditions but the outgoing air stream was configured similar to the conditions as noted above.

Table 4 shows the changes to relative humidity before and after the rotary desiccant wheel in the incoming and outgoing air streams for both the 20 and 32 plate configurations. A

positive value of relative humidity change relates to a decrease in relative humidity and a negative value of relative humidity change relates to an increase in relative humidity.

	20 Plates		32 Plates	
External Air Temp (°C)	Incoming Air Humidity Change	Outgoing Air Humidity Change	Incoming Air Humidity Change	Outgoing Air Humidity Change
25	-1.87	-4.67	2.84	-6.47
30	-1.09	-6.65	4.27	-8.74
35	-0.50	-7.08	5.97	-12.92
40	-1.04	-10.88	8.04	-14.99

5 Table 4 – Regeneration Experiment Results showing Relative Humidity Change in the Incoming and Outgoing Air Channels for 20 and 32 radial plates.

10 The results of table 4 are illustrated in figures 15 and 16. Referring to figure 15, the relative humidity of the income air stream is illustrated for 32 plates (data 178 having linear fit 179) and for 20 plates (data 180 having linear fit 181). Figure 16 shows the change in relative humidity of the outgoing air stream. The 32 plate wheel corresponds to data 184 having line 185 and the 20 plate wheel configuration corresponds to data 182 having linear fit 183.

15 The results from the regeneration experiments show that water molecules can be removed from the pore surface of the silica gel particles, notably, at a higher rate than in the dehumidification experiments. This is likely due to the fact that the regeneration experiments were conducted before the dehumidification experiments and so the silica gel particles were highly saturated, such that more water molecules were available for desorption.

20 The 32 plate configuration showed a higher desorption of water molecules compared to the 20 plate configuration, this is not an unexpected result and likely due to the higher overall number of silica gel particles available, resulting in an increased change in relative humidity. The most interesting result relates to the 20 plate configuration in the incoming air

stream. The negative change in relative humidity indicates that the air stream became more humid after the wheel than before, showing that in fact the silica gel particles in the 20 plate configuration were releasing water molecules to the air stream, albeit at a very low rate. This could provide further evidence that lower regeneration temperatures are possible for the present rotary desiccant wheel.

The volume of silica gel particles in the configuration of a rotary desiccant wheel is a further determining factors in the dehumidification of an air stream, in that without silica gel particles no dehumidification could occur. Finding the optimum volume of silica gel for dehumidification and pressure drop across a rotary desiccant wheel will accordingly help to create a system that is balanced in use.

Three volumes of silica gel were tested to determine the dehumidification of each configuration. The number of plates in the design was altered to increase or decrease the volume of silica gel. The plates were coated with silica gel particles approximately 1 mm in diameter, the volume of silica gel per plate was estimated based on the dimensions of the plates and the size of the particles. From this the total volume of silica gel was calculated.

Each of the configurations were subject to one airstream with high relative humidity and low air temperature and one airstream with low relative humidity (RH) and a regeneration air temperature of 40°C. The two airstreams moved in a counter current direction. The relative humidity and air temperature were measured before and after the rotary desiccant wheel in both airstreams. The change in relative humidity in the high relative humidity airstream can be seen in Table 5 below.

No. of plates	Volume of Silica per Plate (mm ³)	Total Volume of Silica (mm ³)	% Change in RH @ 40°C Regeneration Air Temperature
36	18800	676800	65.53
32	18800	601600	67.01
20	18800	376000	2.55

Table 5 – Change in relative humidity (RH) for different volumes of desiccant.

Table 5 shows an increase in the change of relative humidity between 36 plates and 32 plates and a large decrease in relative humidity between 32 plates and 20 plates. The low change in relative humidity for the 20 plate configuration has previously been noted as an anomalous result due to experimental inaccuracy. It has been determined using data collected from other conditions that this value should be in the range between 45-50%.

Replacing the 2.55% value with the 45- 50% range anticipated for the 20 plate configuration, it is noted from Table 5 that a lower silica gel volume can give a higher percentage change in relative humidity. This is likely due to the volume of air that is able to pass through the plates, in that as more air passes through and comes into contact with the silica, more humidity is removed. As the silica volumes becomes too low, there is not enough contact between the silica and the humid air for dehumidification. The optimum volume of silica gel therefore sits within this range.

An undesirably large pressure drop associated with conventional '*honeycomb*' desiccant wheels is most likely caused by '*skin friction*' between the air flowing through the wheel and the wheel structure. The friction increases the pressure drop across the wheel as the air velocity is reduced. Furthermore, as the 'openings' for individual honeycombs becomes smaller, a phenomenon relating to the velocity of the air arriving at the honeycomb and the size of the honeycomb increases the positive pressure at the inlet side of the wheel which further increases the pressure drop. Accordingly, the present wheel configuration is advantageous by comprising desiccant coated plates that are spaced apart sufficiently within the wheel structure to create '*open*' air flow passageways that minimise '*skin friction*' as far as possible whilst providing sufficient surface area contact with the air flow stream to achieve the desired humidity management (absorption and desorption).

Accordingly, the contact surface area of the desiccant, in the axial direction, was investigated for different wheel configurations in an attempt to optimise the wheel to achieve the smallest possible pressure drop balanced with the desired moisture absorption and desorption.

A ratio of the desiccant (silica gel) at each plate to the total surface area of the wheel in the axial direction was calculated. This ratio provides a quantitative scalable parameter for

wheels of different sizes. The total surface area of the wheel in the axial direction was calculated according to the parameters of Table 6. It should be noted the inside diameters (ID) and the outside diameters (OD) of the wheel for the 36, 32 and 20 plate configurations were ID 6, 7 and 12 and OD 8, 9 and 14 respectively. The ratio of the silica surface area (of the plates) presented to the air flowing in the axial direction through the wheel to the total surface area of the wheel in the axial direction is shown in Table 7 for wheels of different plate configurations including 20, 32 and 36 plates.

No. of Plates	Silica Surface Area per Plate (mm ²)	Total Silica Surface Area (mm ²)	OD Arc Length (mm)	ID Arc Length (mm)	OD Arc Area (mm ²)	ID Arc Area (mm ²)	Total OD Area (mm ²)	Total ID Area (mm ²)
36	18800	676800	20	5	2082	528	83273	21112
32	18800	601600	22	6	2342	616	84314	22167
20	18800	376000	35	10	3643	1056	87437	25334

10 Table 6 – Parameters for the calculation of the total surface area of the wheel in the axial direction for three wheel configurations.

No. Of plates	Silica surface area per plate (mm ²)	Total silica surface area (mm ²)	Total wheel surface area (mm ²)	Silica surface/total wheel surface
36	18800	676800	781184.65	0.87
32	18800	601600	708081.14	0.85
20	18800	376000	488770.61	0.77

15 Table 7 – Ratio of the silica surface area (presented to the air flowing in the axial direction through the wheel) to the total surface area of the wheel (in the axial direction) for wheels including 20, 32 and 36 plates.

Additionally, the volume of desiccant of the wheel with 20, 32 and 36 plates has also been determined and defined as a ratio of the total air sector volume, where this latter term refers to the total volume of air that is capable of passing through the wheel in a given instant. This corresponds to the volume of air per sector multiplied by the spaces between the blades. That is, for 36 blades there are 40 spaces, for 32 blades there are 36 spaces and for 20 blades there are 24 spaces. The volume of air per sector is the volume between two individual blades for a given configuration. This was obtained by calculating the area of the large sector (OD) minus the smaller sector (ID) multiplied by the height of the wheel in the axial direction. The ratio of the volume of silica to total air sector volume is shown in Table 8.

No. Of plates	Volume of silica per plate (mm ³)	Total volume of silica (mm ³)	Volume of air per sector (mm ³)	Total air sector volume (mm ³)	Volume of silica/total air sector volume
36	18800	676800	128708	5148302	0.13
32	18800	601600	144293	5194561	0.12
20	18800	376000	222222	5333335	0.07

Table 8 –Ratio of the volume of silica to total air sector volume.

It is noted from Table 7 that the ratio of desiccant surface area to total wheel surface area is in a range 0.5 to 1, preferably 0.6 to 0.9 and more preferably 0.7 to 0.9. Additionally, the volume of desiccant to total air sector volume is in a range 0.01 to 0.3, 0.02 to 0.2, 0.03 to 0.18 and more preferably 0.04 to 0.15.

As noted previously, the pressure drop across the wheel should be as low as possible in order for unimpeded air flow through the wheel to achieve the desired level of ventilation. Due to the necessary rotation of the wheel for ongoing dehumidification, a range of rotation speeds was measured to understand the effect on the pressure drop. The range was calculated for 20, 32 and 36 plate configurations and the results are shown in Table 9. Two expected trends can be seen from the data. As the number of plates increases, the pressure drop increases. This is obvious as the increased blockage of the air (by the wheel with increasing

number of plates) will increase the pressure drop. Further, as the rotation speed of the wheel increases, the pressure drop increases. Again, the increased rotation speed will act similar to increased blockage, increasing the pressure drop. The data shows that the 20x3mm blade configuration provides the lowest pressure drop. Above a rotation speed of 30rpm, it is unlikely that contact between the air and silica would be sufficient to enable dehumidification, therefore this configuration was not tested.

	0rpm	5rpm	10rpm	15rpm	20rpm	25rpm	30rpm
36x3mm	2.77	2.78	2.74	2.84	2.78	2.78	2.80
32x3mm	2.65	2.67	2.63	2.64	2.64	2.66	5.23
20x3mm	2.36	2.26	2.30	2.26	2.22	2.26	2.26

Table 9 – Wheel rotation speeds and their effect on the pressure drop across the wheel calculated for 20, 32 and 36 plate configurations.

Accordingly, an optimum rational speed of the present wheel, R may be in the range $5 \text{ rpm} \leq R \leq 30 \text{ rpm}$, $10 \text{ rpm} \leq R \leq 20 \text{ rpm}$ and more preferably $15 \text{ rpm} \leq R \leq 20 \text{ rpm}$ to allow effective heat transfer and dehumidification.

To minimize the pressure drop across the wheel and maximize dehumidification management, it is preferred that the plates of the wheel are solid and planar in the axial direction so as to be aligned parallel with the direction of air flow through the wheel. Such a configuration is advantageous to reduce the pressure drop across the wheel as much as possible. In particular, it is advantageous to provide solid plates and not plates having open or mesh-like structures which may otherwise create turbulence between the plates and the fluid that accordingly will increase the pressure drop. Furthermore, curved or twisted plates (in the axial or radial directions) are also considered disadvantageous to increase the pressure drop for the same reasons. Accordingly, the plates of the present desiccant wheel comprise substantially planar surfaces (substantially flat main surfaces) formed from solid material that is then coated with desiccant.

Although particular embodiments of the invention have been described, it will be appreciated that many modifications/additions and/or substitutions may be made within the scope of the claimed invention.

CLAIMS

1. A rotary desiccant wheel for a passive ventilation system, wherein the wheel has a surface coated with a desiccant for adsorbing moisture from air flowing through the system, and wherein the wheel has a porosity ϕ greater than or equal to approximately 65%.
5
2. The rotary desiccant wheel of claim 1, comprising a plurality of plates coated with said desiccant.
10
3. The rotary desiccant wheel of claim 2, wherein the plates are aligned parallel to a direction of air flow within the system to allow air flowing through the system to pass over first and second opposite surfaces of the plates.
- 15 4. The rotary desiccant wheel of claim 2 or claim 3, wherein the plates are removably mounted on a body portion of the wheel.
5. The rotary desiccant wheel of any of claims 2 to 4, wherein the plates extend radially outward from central axle of the wheel.
20
6. The rotary desiccant wheel of any preceding claim, comprising a plurality of concentric rings coated with said desiccant.
7. The rotary desiccant wheel of claim 6, wherein a central axis of the concentric rings is aligned parallel to a direction of air flow within the system to allow air flowing through the system to pass over an inner surface and an outer surface of each ring.
25
8. The rotary desiccant wheel of any preceding claim, wherein the wheel has a porosity ϕ greater than or equal to approximately 66.1%.
- 30 9. The rotary desiccant wheel of claim 8, wherein the wheel has a porosity ϕ greater than or equal to approximately 67%.

10. The rotary desiccant wheel of claim 9, wherein the wheel has a porosity ϕ greater than or equal to approximately 70.7%.
- 5 11. The rotary desiccant wheel of claim 9, wherein the wheel has a porosity ϕ greater than or equal to approximately 73.5%.
12. The rotary desiccant wheel of any preceding claim, wherein the volume V_d of the desiccant covering the surface of the wheel is in the range $3.7 \times 10^{-4} \text{ m}^3 \leq V_d \leq 9.0 \times 10^{-4} \text{ m}^3$.
- 10 13. The rotary desiccant wheel as claimed in any preceding claim, when dependent on claim 2 wherein the quotient of: a total surface area of desiccant in an axial direction of the wheel/a total surface area of the wheel in the axial direction including and defined by a radially inward facing outer surface, a radially outward facing inner surface and the respective surfaces of the plates positioned between the inward and outward facing surfaces is in a range 0.5 to 1.0.
- 15 14. The rotary desiccant wheel as claimed in claim 13 wherein the quotient is in a range 0.6 to 0.9.
- 20 15. The rotary desiccant wheel as claimed in claim 13 wherein the quotient is in a range 0.7 to 0.9.
- 25 16. The rotary desiccant wheel as claimed in any preceding claim when dependent on claim 2 wherein the quotient of: a total volume of desiccant covering at least one surface of the wheel/a total air sector volume, where the total air sector volume is the free volume of air between neighbouring plates multiplied by the number of spaces defined between the plates is 0.01 to 0.3.
- 30 17. The rotary desiccant wheel as claimed in claim 16 wherein the quotient is 0.02 to 0.2.
18. The rotary desiccant wheel as claimed in claim 16 wherein the quotient is 0.03 to 0.18.

19. The rotary desiccant wheel as claimed in claim 16 wherein the quotient is 0.04 to 0.15.
20. A passive ventilation system comprising the rotary desiccant wheel of any preceding
5 claim for adsorbing moisture from air flowing through the system.
21. The passive ventilation system of claim 20, wherein the rotary desiccant wheel is configured to:
- 10 adsorb moisture from air flowing in a first direction in the system; and
 transfer at least some of the moisture to air flowing in a second direction in the system.
22. The passive ventilation system of claim 21, wherein the rotary desiccant wheel is operable to rotate so that each part of the surface coated with a desiccant is:
- 15 exposed to air flowing in the first direction during a first part of its rotation;
 and
 exposed to air flowing in the second direction during a second part of its rotation.
- 20 23. The passive ventilation system of claim 21 or claim 22, further comprising a duct having a plurality of channels for separating air flowing in the first direction in the duct from air flowing in the second direction in the duct.
24. The passive ventilation system of any of claims 20 to 23, wherein the passive
25 ventilation system comprises a wind tower for a building, the wind tower comprising:
 an opening for allowing air to enter and exit the tower; and
 a duct for allowing air to flow between an interior of the building and the opening,
 wherein the rotary desiccant wheel is positioned in the wind tower for adsorbing
30 moisture from air flowing from the opening of the wind tower to the interior of the building.

25. The passive ventilation system of claim 24, wherein the rotary desiccant wheel is positioned in the wind tower to:
- adsorb moisture from air flowing from the opening of the wind tower to the interior of the building; and
- 5 transfer at least some of the moisture to air flowing from the interior of the building to the opening of the wind tower.
26. A building comprising a passive ventilation system according to any preceding claim.
- 10 27. A method of retrofitting a passive ventilation system, the method comprising:
- positioning a rotary desiccant wheel according to any of claims 1 to 12 in the passive ventilation system to adsorb moisture from air flowing through the system.
28. The method of claim 27, wherein the passive ventilation system comprises a wind
- 15 tower for a building, the wind tower comprising:
- an opening for allowing air to enter and exit the tower, and
- a duct for allowing air to flow between an interior of the building and the opening,
- the method further comprising:
- 20 positioning the rotary desiccant wheel in the wind tower, for adsorbing moisture from air flowing from the opening of the wind tower to the interior of the building.
29. A rotary desiccant wheel substantially as hereinbefore described, with reference to the
- 25 accompanying drawings.
30. A building comprising a wind tower substantially as hereinbefore described, with reference to the accompanying drawings.
- 30 31. A method of passive ventilation of a building comprising:
- allowing an inward flow of air from an external region of a building into an interior of the building via a wind tower;
- allowing rotation of a desiccant wheel positioned within the wind tower;

adsorbing moisture from the inward flow of air at the desiccant wheel;

allowing an outward flow of air from the interior of the building through the wind tower to the external region of the building;

5 allowing moisture adsorbed at the desiccant wheel to transfer from the desiccant wheel to the outward flow of air through the wind tower;

wherein the desiccant wheel comprises a surface coated with a desiccant for adsorbing the moisture from the inward flow of air flowing through the wind tower, the desiccant wheel having a porosity ϕ greater than or equal to approximately 65%.

10 32. The method as claimed in claim 31 comprising controlling the rotational speed of the desiccant wheel to be in the range 5 rpm to 30 rpm.

33. The method as claimed in claim 31 comprising controlling the rotational speed of the desiccant wheel to be in the range 10 rpm to 20 rpm.

15 34. The use as claimed in claim 31 comprising controlling the rotational speed of the desiccant wheel to be in the range 15 rpm to 20 rpm.

20 35. A method of retrofitting a wind tower, the method being substantially as hereinbefore described, with reference to the accompanying drawings.

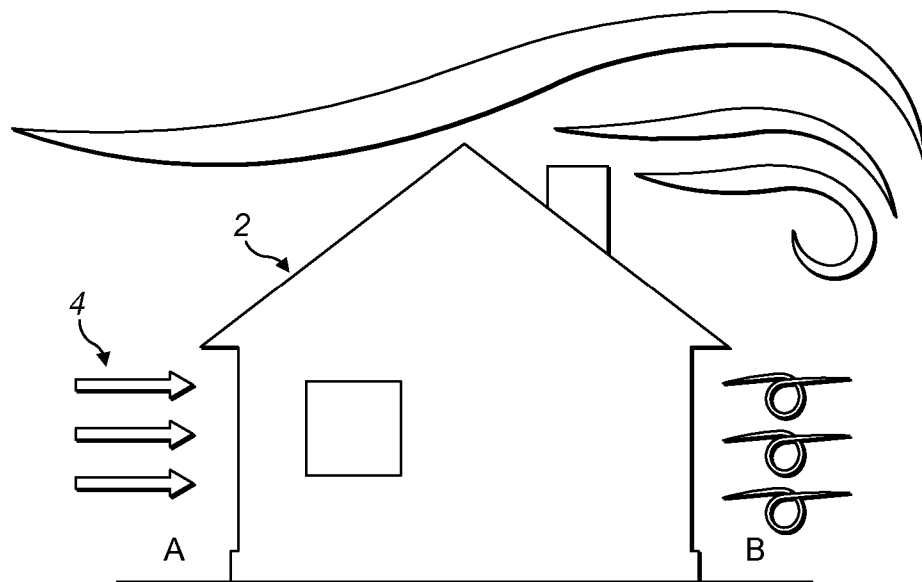


FIG. 1

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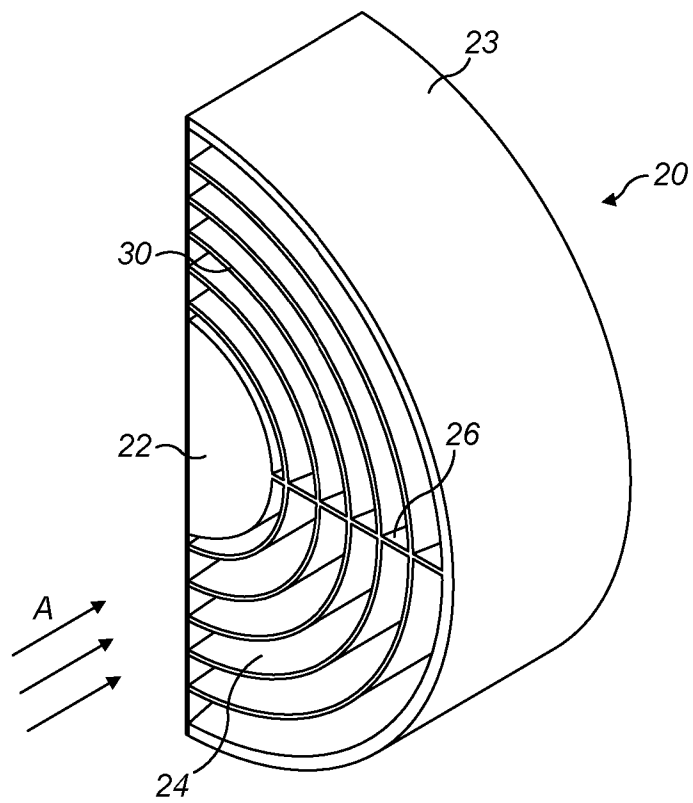


FIG. 2

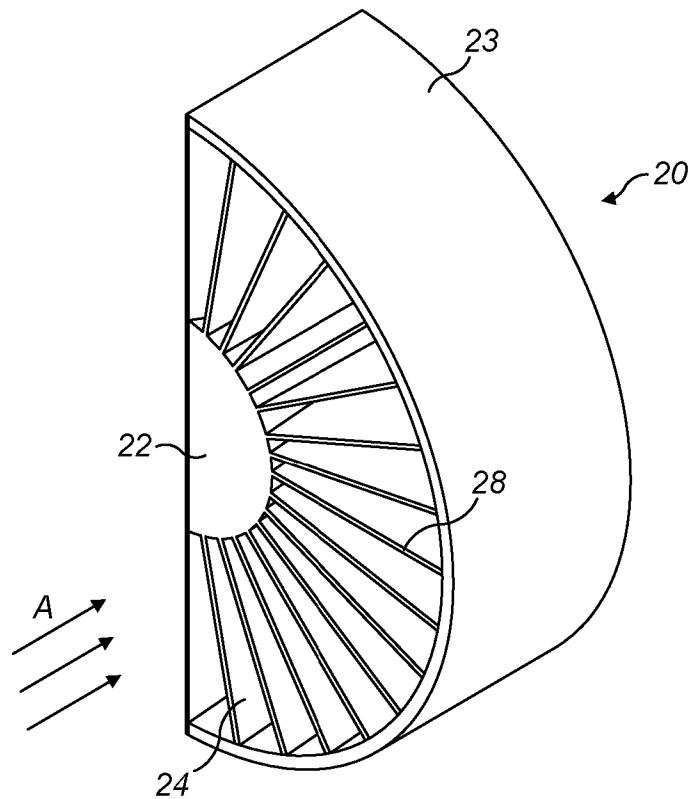


FIG. 3

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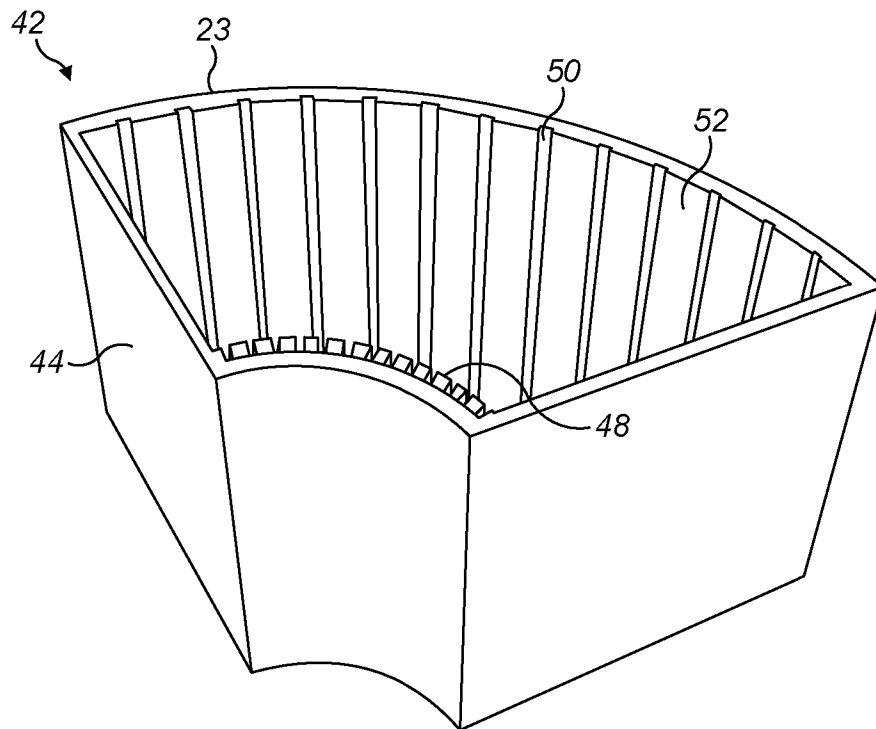


FIG. 4

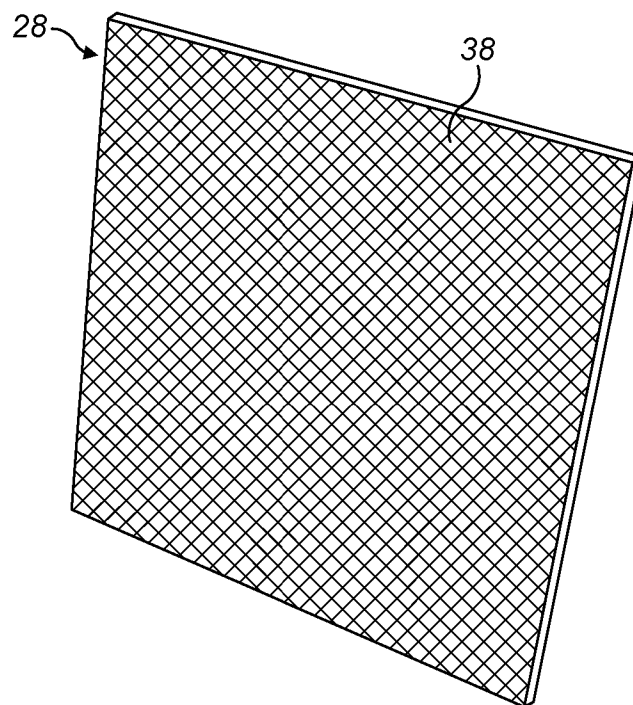


FIG. 5

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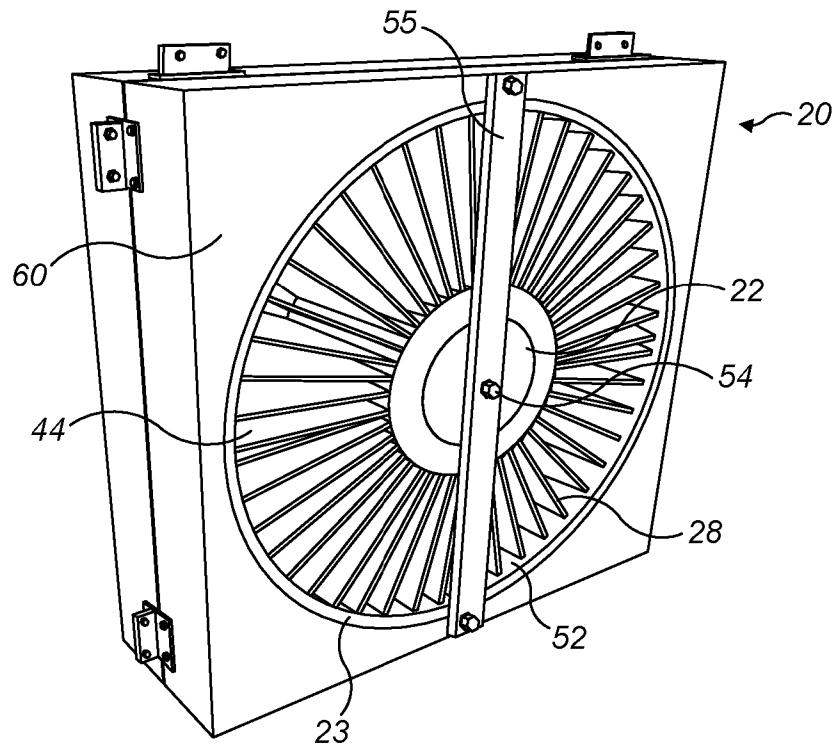


FIG. 6

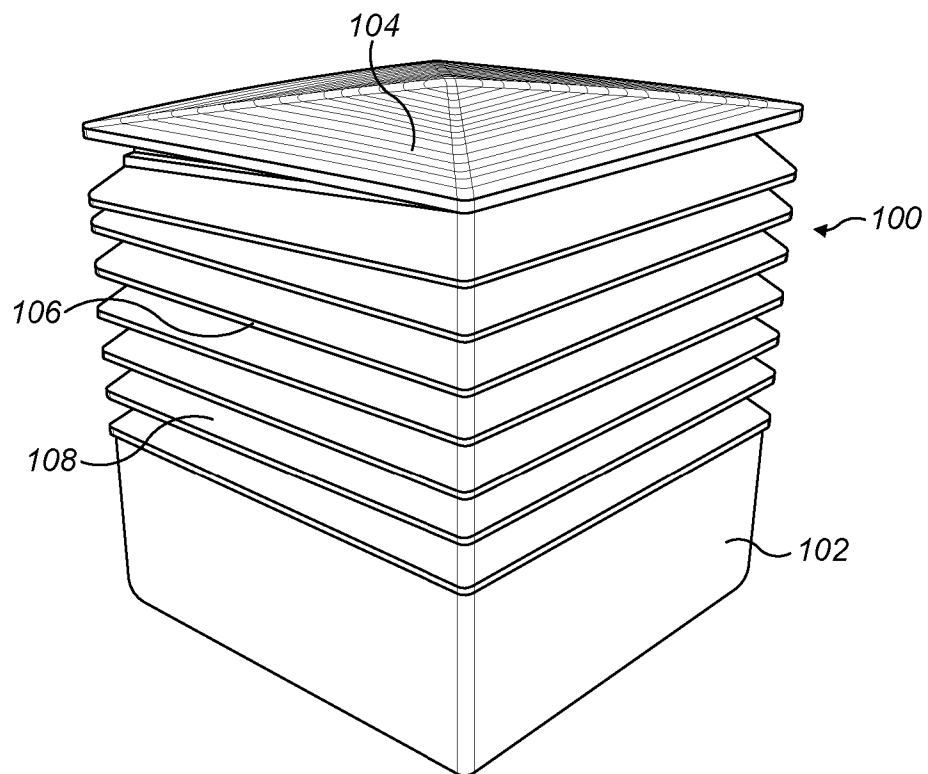


FIG. 7

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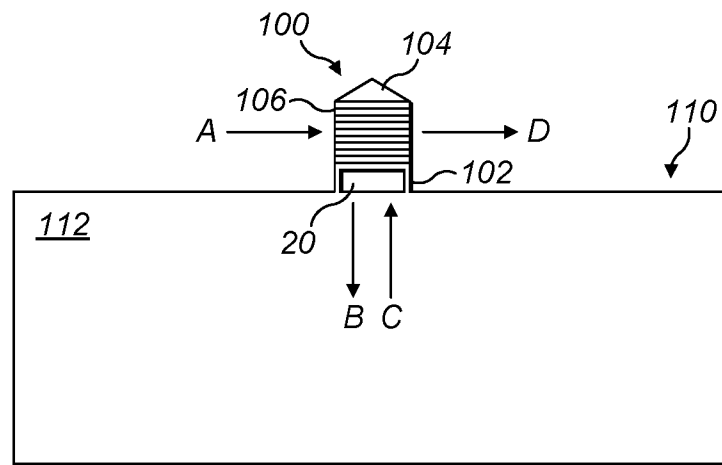


FIG. 8

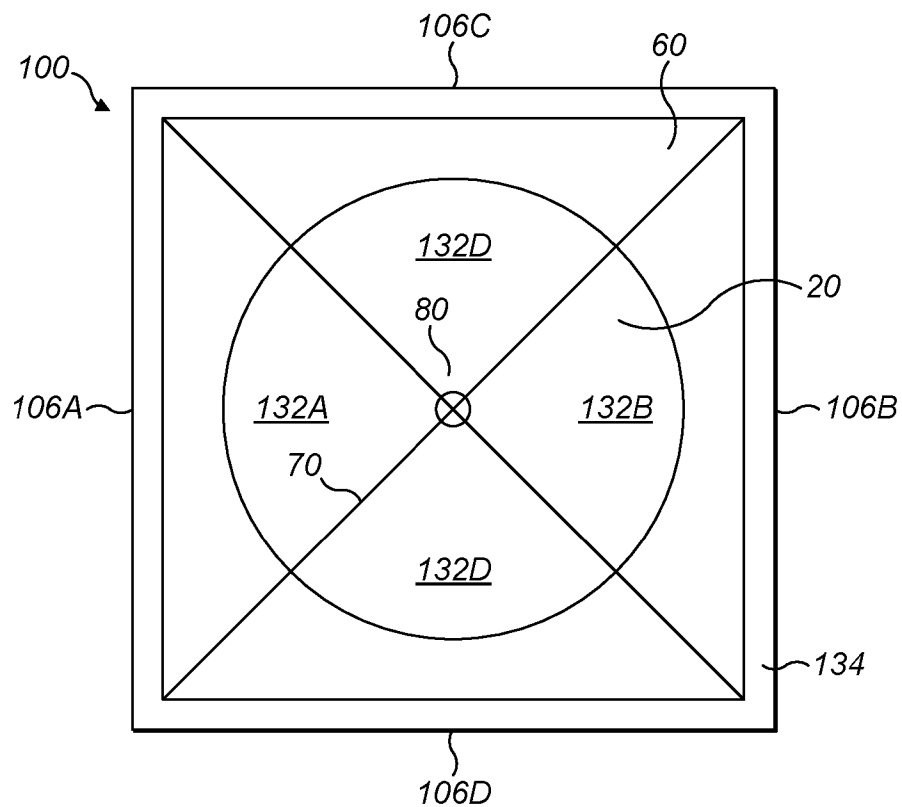
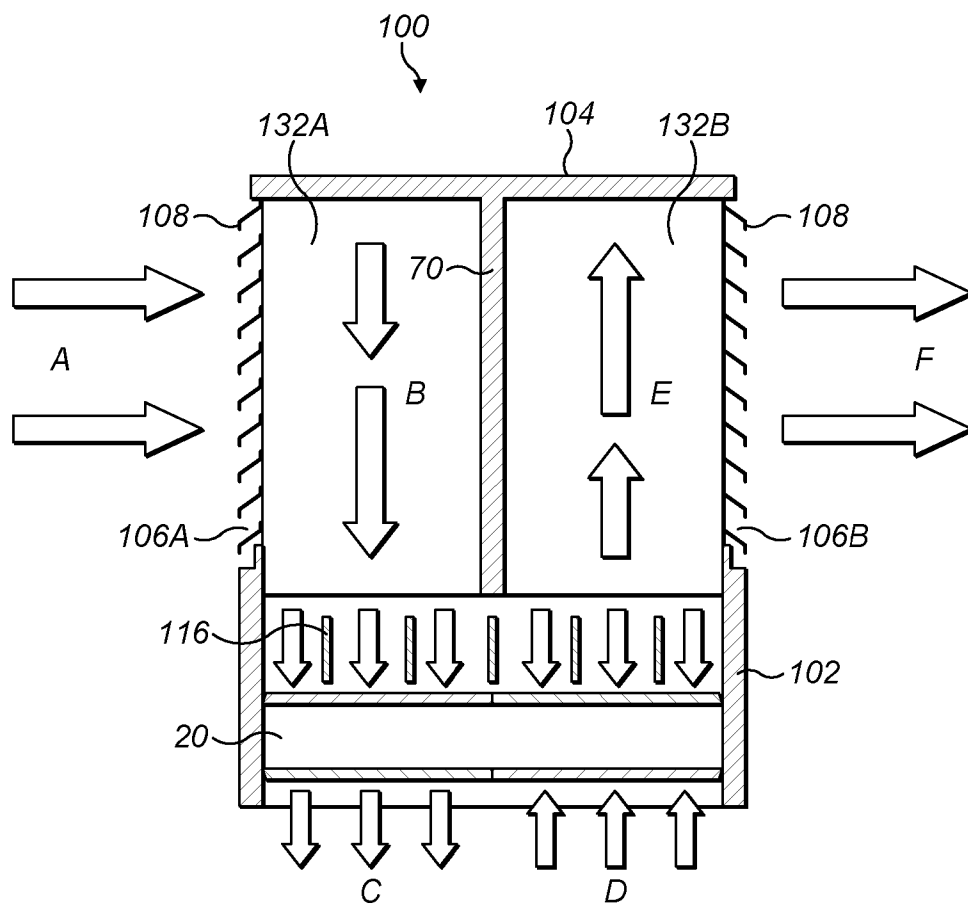
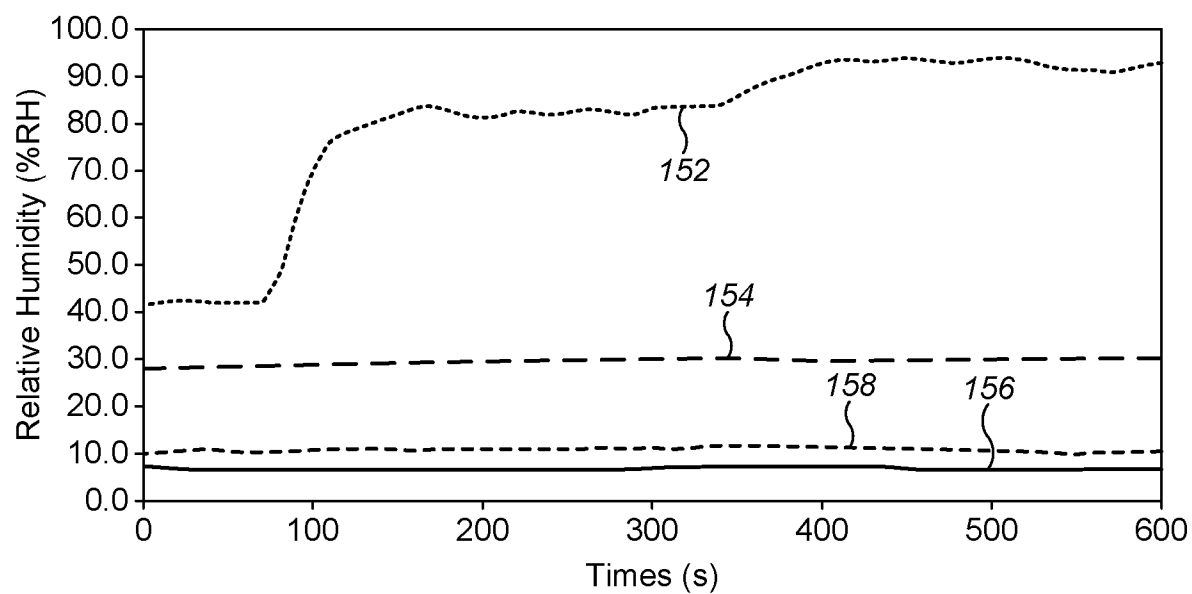
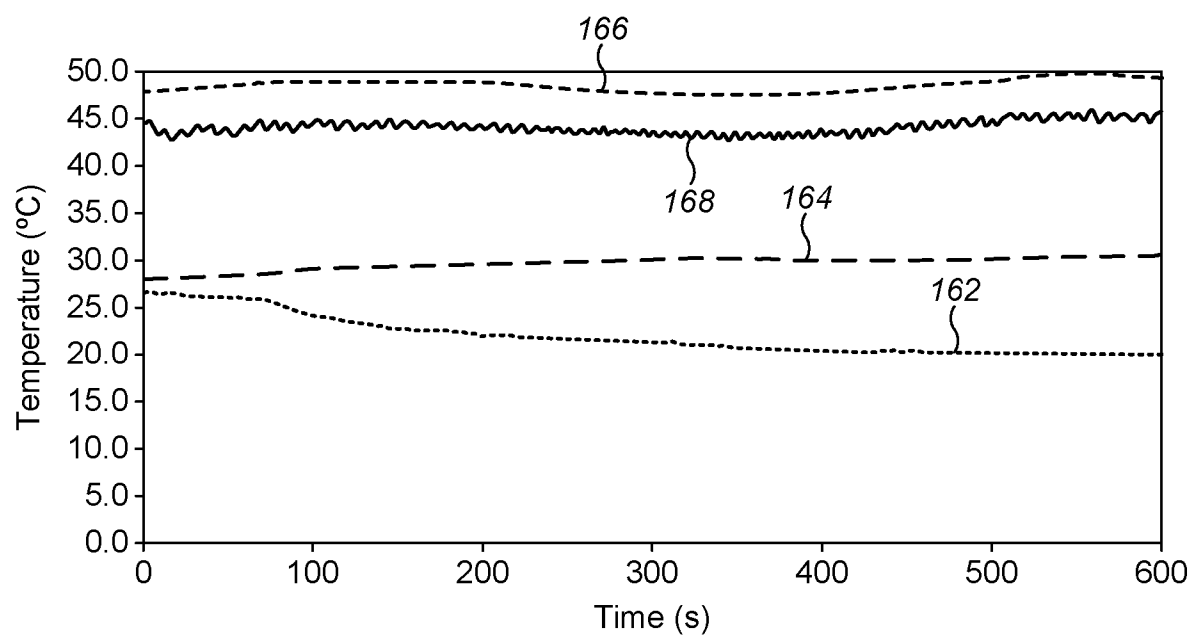


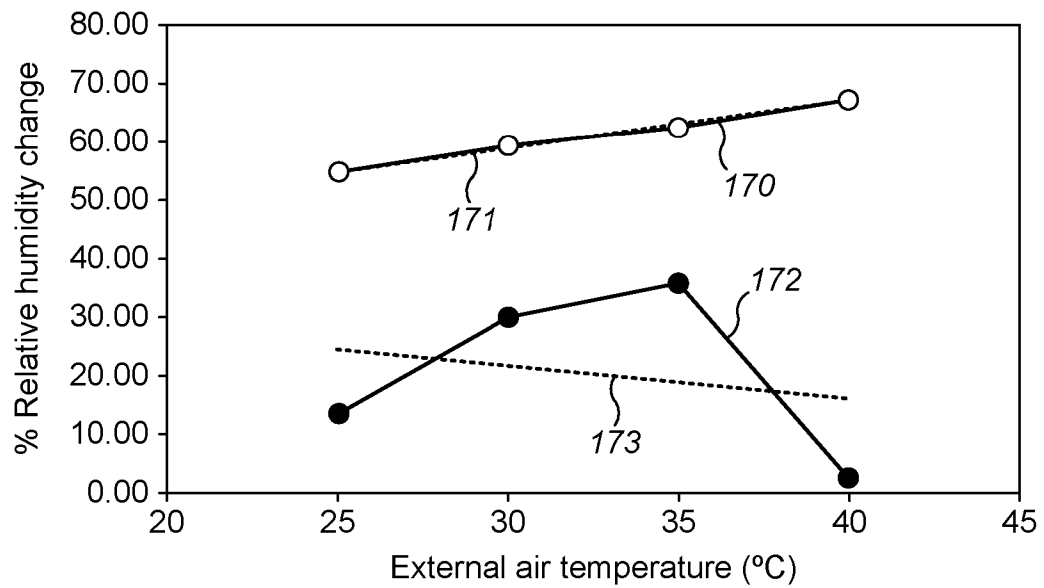
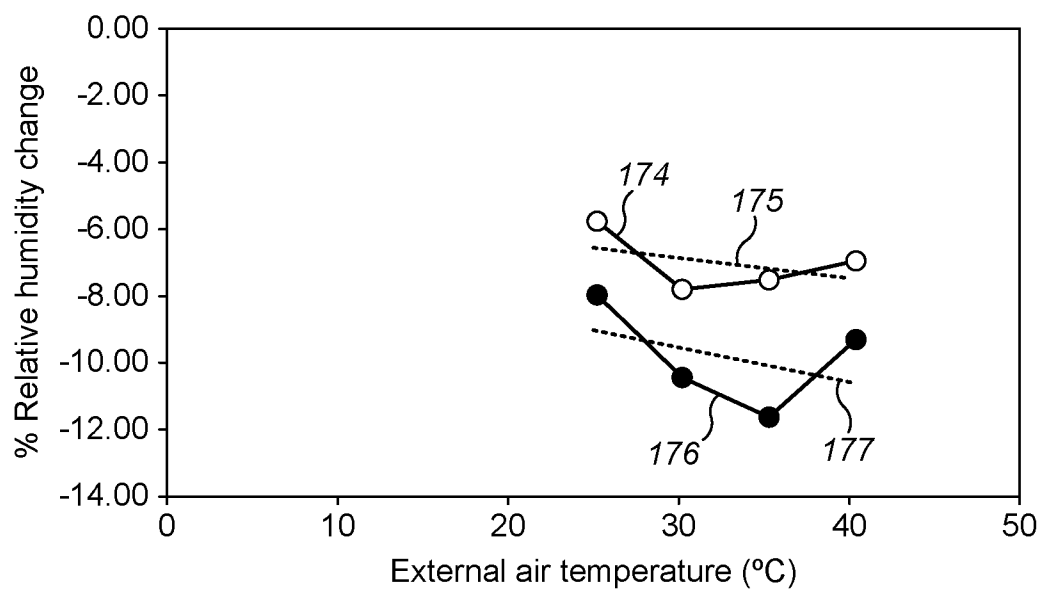
FIG. 9

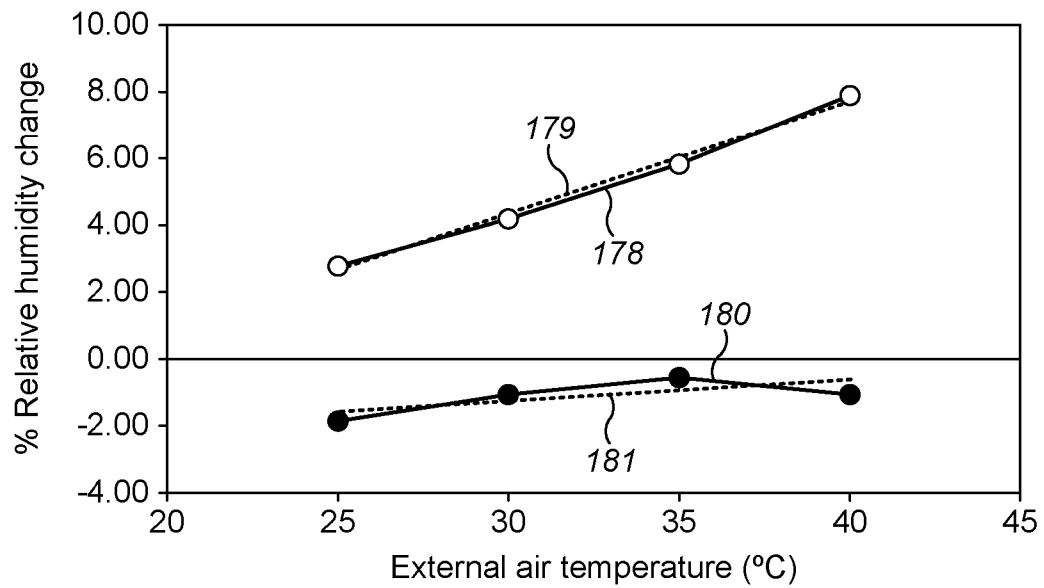
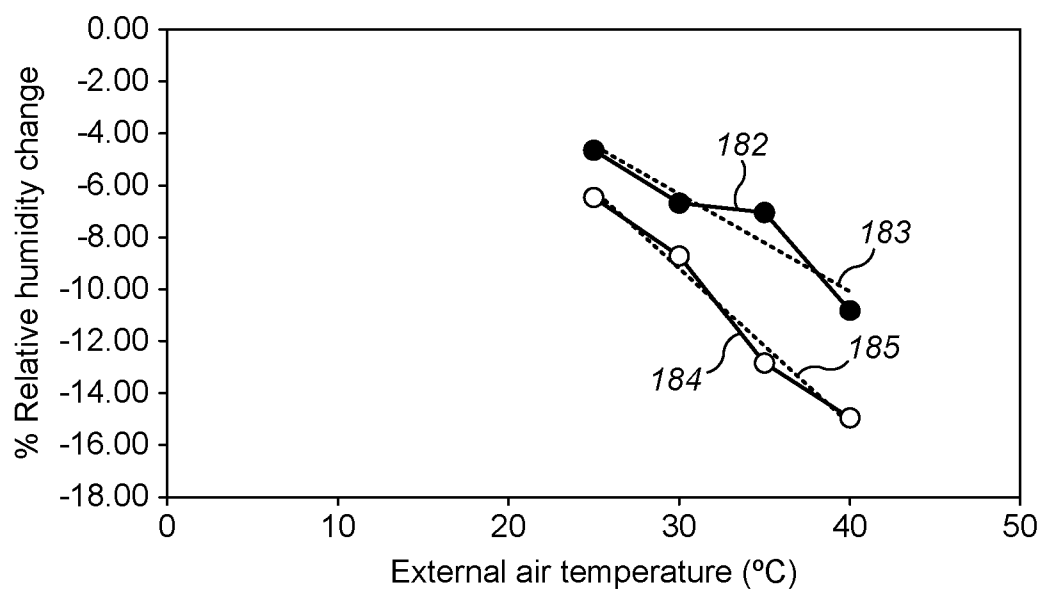
**FIG. 10**

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**FIG. 11****FIG. 12**

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**FIG. 13****FIG. 14**

**FIG. 15****FIG. 16**

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/051081

A. CLASSIFICATION OF SUBJECT MATTER

INV. B01D53/04 B01D53/06 B01D53/26 F24F3/14
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)

B01D F24F

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)

EP0-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.
X	US 5 069 272 A (CHAGNOT BRUCE J [US]) 3 December 1991 (1991-12-03) cited in the application column 1, lines 5-13 column 2, lines 47-63 column 4, line 61 - column 5, line 10; claims; figures -----	1,8-23, 26,27
X A	US 5 733 451 A (COELLNER JAMES A [US] ET AL) 31 March 1998 (1998-03-31) column 2, line 59 - column 3, line 9 column 3, lines 42-56 column 5, lines 13-30 column 6, lines 14-18 column 6, line 41 - column 7, line 8; figures ----- -/--	1-23,26, 27 24,25, 28,31-34



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

24 June 2016

Date of mailing of the international search report

13/07/2016

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Authorized officer

Persichini, Carlo

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2016/051081

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 4 093 435 A (MARRON ALBERT J ET AL) 6 June 1978 (1978-06-06) column 2, lines 16-25 column 3, line 61 - column 4, line 17 column 9, line 21 - column 10, line 3; example 1 -----	1-23,26, 27 24,25, 28,31-34
X A	US 3 713 281 A (ASKER G ET AL) 30 January 1973 (1973-01-30) example 1 -----	1-23,26, 27 24,25, 28,31-34
A	BEN RICHARD HUGHES ET AL: "The development of commercial wind towers for natural ventilation: A review", APPLIED ENERGY, ELSEVIER SCIENCE PUBLISHERS, GB, vol. 92, 25 November 2011 (2011-11-25), pages 606-627, XP028356931, ISSN: 0306-2619, DOI: 10.1016/J.APENERGY.2011.11.066 [retrieved on 2011-12-01] cited in the application the whole document -----	1-28, 31-34

INTERNATIONAL SEARCH REPORT

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