



(51) International Patent Classification:  
A47F 3/04 (2006.01)

(21) International Application Number:  
PCT/US2014/049411

(22) International Filing Date:  
1 August 2014 (01.08.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
61/861,870 2 August 2013 (02.08.2013) US

(71) Applicants: **THE UNIVERSITY OF FLORIDA RESEARCH FOUNDATION, INC.** [US/US]; 233 Grinter Hall, Gainesville, FL 32611 (US). **COOL FLOW DYNAMICS, INC.** [US/US]; 4457 Sandpine Lane, Sarasota, Florida 34241 (US).

(72) Inventors: **WATANABE, Kahoru**; 4457 Sandpine Lane, Sarasota, Florida 34241 (US). **ROY, Subrata**; 8722 NW 9th Place, Gainesville, FL (US).

(74) Agents: **GRIGGERS, Charles** et al.; Thomas/horstemeyer, LLP, 400 Interstate North Parkway, SE, Suite 1500, Atlanta, GA 30339 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

[Continued on next page]

(54) Title: OPEN REFRIGERATION UNITS USING INDUCED JET ACTUATORS

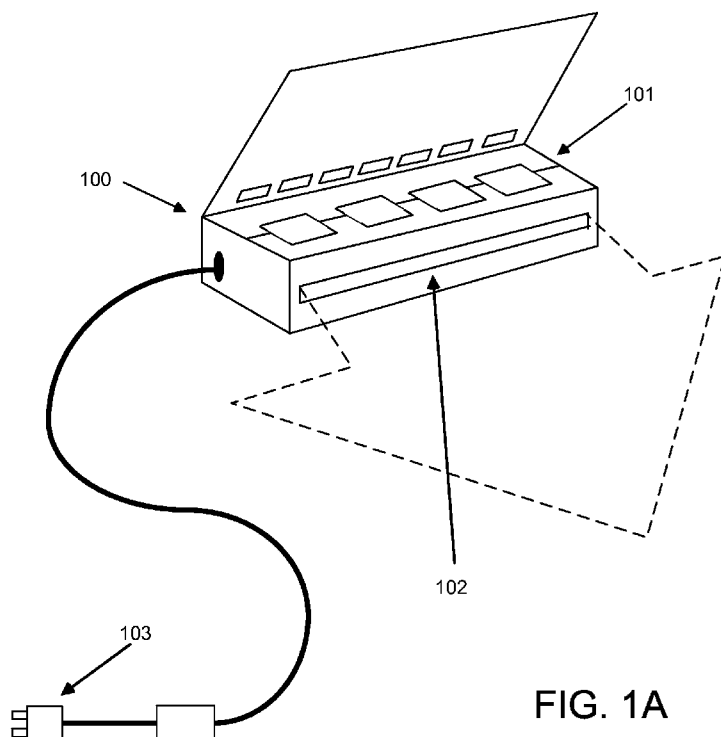


FIG. 1A

(57) Abstract: The present disclosure includes an open refrigeration apparatus having a case that includes a product holding volume for holding one or more products and defines at least one open face through which the product holding volume can be accessed, a cooling unit to cool the product holding volume in the case, and a first induced jet actuator unit having one or more air outflow vents positioned with respect to the case to create an air flow from the air outflow vents at least generally parallel to the open face to separate the product holding volume from an ambient volume outside of the case.



TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, —  
KM, ML, MR, NE, SN, TD, TG).

*before the expiration of the time limit for amending the  
claims and to be republished in the event of receipt of  
amendments (Rule 48.2(h))*

**Published:**

— *with international search report (Art. 21(3))*

## **OPEN REFRIGERATION UNITS USING INDUCED JET ACTUATORS**

### **CROSS-REFERENCE TO RELATED APPLICATION**

**[0001]** This application claims priority to copending U.S. provisional application entitled, "Method and Apparatus for Improving the Efficiency of Open Refrigeration Units using Synthetic Jet Actuators," having serial number 61/861,870, filed August 2, 2013, which is entirely incorporated herein by reference.

### **TECHNICAL FIELD**

**[0002]** The present disclosure is generally related to open-case refrigeration technologies.

### **BACKGROUND**

**[0003]** Retailers frequently use open refrigeration for some or all of their refrigerated items. Open-case refrigerators can be found in virtually every grocery store, supermarket, and convenience store. These units keep eggs, meats, cheeses, and other food and beverages cold while displaying them in a manner that is attractive and inviting to customers. The major downside of open-case refrigerators is that their open fronts are extremely inefficient, resulting in sky-high energy bills, losing on average 75% of the energy used to operate it.

**[0004]** Open-case units can be replaced with units equipped with doors or retrofitted with doors to achieve energy savings; however, opening a physical door can pull cold air out of the case as it breaks the seal within the refrigerated space. One study showed that when a refrigeration unit's door is opened over 60 times in

one hour, it negates any energy savings. Opening doors can also be cumbersome in high traffic areas, and the doors tend to require frequent cleaning. There is also a substantial cost associated with replacing open-case units or retrofitting them with doors. Perhaps more importantly, placing a physical barrier between the customer and the product tends to reduce sales, and this loss in sales has been shown to negate the energy savings that the doors provide in some circumstances. Commercial retailers therefore still make extensive use of open refrigeration units despite their substantial inefficiencies.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0005]** Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

**[0006]** FIG. 1A is a diagram of a perspective view of an illustrative housing device which contains induced jet actuators in accordance with an embodiment of the present disclosure.

**[0007]** FIG. 1B is a diagram of a side elevation of the illustrative housing device of FIG. 1A.

**[0008]** FIG. 1C is a diagram of a bottom elevation of the illustrative housing device of FIG. 1A, which shows an interior configuration within the housing.

**[0009]** FIGS. 1D and 1E are diagrams of respective perspective and side views of an illustrative housing device which shows the induced jet actuators being housed inside and accessible from an opening in the bottom.

**[0010]** FIG. 2A is a diagram of a perspective view of the illustrative housing device of Fig. 1A showing a housing device enclosure and mounting plate which can be customized to fit existing refrigeration units.

**[0011]** FIG. 2B is a diagram of a side elevation of the illustrative housing device of FIG. 1A showing its angling capabilities.

**[0012]** FIG. 3A is a diagram of a perspective view of the illustrative housing device of FIG. 1A and potential accessories prior to installation onto an existing vertically oriented refrigeration unit.

**[0013]** FIG. 3B is a diagram of a perspective view showing how the illustrative housing device of FIG. 1A can be attached to an existing refrigeration unit in accordance with an embodiment of the present disclosure.

**[0014]** FIG. 4A is a diagram of a side elevation of an illustrative vertically oriented refrigeration unit before upgrade.

**[0015]** FIG. 4B is a diagram of a side elevation of the vertically oriented refrigeration unit showing where the illustrative housing device and potential accessories could attach in accordance with an embodiment of the present disclosure.

**[0016]** FIG. 4C is a diagram of a side elevation of the vertically oriented refrigeration unit with the illustrative housing device and accessory attached, showing air flow from the device and an interior flow of cold air being contained.

**[0017]** FIG. 5A is a diagram of a side elevation of a horizontally oriented refrigeration unit before upgrade.

**[0018]** FIG. 5B is a diagram of a side elevation of the horizontally oriented refrigeration unit showing where the housing device and potential accessories can attach in accordance with an embodiment of the present disclosure.

**[0019]** FIG. 5C is a diagram of a side elevation of the horizontally oriented refrigeration unit with the illustrative housing device and accessory attached, showing air flow from the device and an interior flow of cold air being contained.

**[0020]** FIG. 5D is a diagram of a side elevation of the horizontally oriented refrigeration unit showing where the housing device and accessory attach in accordance with an embodiment of the present disclosure showing internal air rotation.

**[0021]** FIG. 6A is a diagram of a side elevation of a vertically oriented refrigeration unit showing where multiple illustrative housing devices and potential accessories can attach in accordance with an embodiment of the present disclosure.

**[0022]** FIG. 6B is a diagram of a front elevation of a vertically oriented refrigeration unit showing where multiple illustrative housing devices and potential accessories can attach in accordance with an embodiment of the present disclosure.

**[0023]** FIG. 7 is a diagram of a vertically oriented refrigeration unit with illustrative housing units of induced jet actuators attached in accordance with an embodiment of the present disclosure.

**[0024]** FIGS. 8A is a diagram of a perspective elevation of a refrigeration unit and the effect a penetrating arm or object would have on the air flow that is being released in a waterfall effect manner in accordance with an embodiment of the present disclosure.

**[0025]** FIG. 8B is a diagram of a perspective view of a vertical open case refrigeration unit showing the door being opened and cold air being released from the interior of the unit.

**[0026]** FIG. 8C is a diagram of a top view of the vertical open case refrigeration unit of FIG. 8B showing the door being opened and cold air being released from the interior of the unit.

**[0027]** FIG. 9A is a diagram of a cold air curtain in a vertical open refrigeration display case under the current state of the art.

**[0028]** FIG. 9B is a diagram of multiple air curtains in a vertical open refrigeration display case under the current state of the art.

**[0029]** FIG. 10 is a chart of energy losses experienced by refrigeration units under the current state of the art.

**[0030]** FIG. 11 is a diagram of a refrigeration unit having a back panel fitted with synthetic jet actuator(s) in accordance with an embodiment of the present disclosure.

**[0031]** FIG. 12 is a diagram of a refrigeration unit having a back and front of the unit fitted with induced jet actuator(s) in accordance with an embodiment of the present disclosure.

**[0032]** FIG. 13 is a diagram of a refrigeration unit under the current state of the art having back and front of the unit interiors being fitted with induced jet actuators. The figure further shows induced jet actuators being fitted in the mechanical portion of the refrigeration unit including access point for accessories to be integrated into state of the art system designs.

### **DETAILED DESCRIPTION**

**[0033]** Systems according to the present disclosure can help to reduce the substantial energy costs exhibited by prior-art open refrigeration units or cases in retail establishments. The cost reductions can be very significant given the large numbers of units in operation and the high levels of energy that they consume. These cost reductions can result both from better containment of the cold air and reduction of the intrusion of the ambient air, which reduces the power consumption of the unit to maintain its optimal operating temperatures.

**[0034]** FIG. 1A shows an illustrative housing device in accordance with an embodiment of the present disclosure which contains induced jet actuators and which can be opened and closed to access internal components using hinges 100 that run along a length of the device. The induced jet actuators 101 are installed along the length of the device, such as in parallel. The opening vent(s) 102 or port(s) can exclusively provide the outflow from the induced jet actuators, or depending on the type of induced jet actuator used, can also be the intake. The vents can be of any suitable shape such as one or more linear slots. The power cord 103 for the system can be designed to plug into commonly available power outlets and its input will be managed by a power converter device that is configured

to the specific needs of the induced jet actuators in accordance with an embodiment of the present disclosure.

**[0035]** In various embodiments, induced jet actuators attached to a refrigeration unit or case release bursts of fast moving air to create a "waterfall effect" that forms a virtual door which is more difficult for ambient air to penetrate from the outside, while reducing cold air loss from the inside being released into the ambient air. The bursts of air move almost parallel across an open surface of a refrigerated case. As mentioned, because the air flow being released from the system will be relatively faster than the air moving within the refrigeration unit, an induced jet actuator air flow takes on the characteristics of a solid surface or a waterfall effect as it moves across the outside of the refrigerated area. This type of fluid flow is also referred as a free shear layer, as understood by one of ordinary skill in the art.

**[0036]** The waterfall effect of fast moving of air creates separation between the refrigerated interior air and the exterior ambient air. The slower moving refrigerated air (i.e., operates at a lower air speed) is less able to penetrate, mix in with, or escape the wall of faster moving air, and the ambient air is unable to penetrate through the "wall" into the refrigerated space. The result reduces the loss of cool air and thus reduces the amount of energy necessary to maintain the desired cool temperatures within the system. Further, the induced jet actuators operate to produce the air flow independently of any mechanically linked moving parts and by deformation of pumping elements.

**[0037]** In one general aspect, this application discloses an embodiment of a self-contained add-on device designed to create a virtual door by mimicking a solid

surface using induced jet actuators which release micro bursts of air. This device may be designed for use on commercial refrigeration display units which are not physically enclosed. In one embodiment, a plug and play feature allows the system to be installed easily, quickly, and with minimal wiring or impact on existing retail operations.

**[0038]** In various embodiments, systems according to the present disclosure use synthetic jet actuators as induced jet actuators, which come in multiple known styles including, Piezoelectric Synthetic Jet Actuator, Synthetic Jet Plasma Actuator, Synthetic Jet Circular Orifice Actuator, Synthetic Slot Jet Actuator, Electro-active Polymer Synthetic Jet Actuator, No-moving-part Hybrid Synthetic Jet Actuator. Any, all, or a combination of these devices known or unknown may be used and the multiple installation configurations contemplated.

**[0039]** Additionally, plasma technology used by one embodiment of induced jet actuators has the potential to create a new generation of energy efficient, open refrigeration systems that will improve the quality of a shopping experience for people everywhere. Plasma consists of charged species, namely electrons and ions that bombard the air particles with sufficient momentum to motivate the neighboring flow. Non-limiting examples of plasma actuators are described in U.S. Patent No. 8,235,072, titled "Method and Apparatus for Multibarrier Plasma High Performance Flow Control," issued on August 7, 2012, U.S. Publication No. 2013/0038199, titled "System, Method, and Apparatus for Microscale Plasma Actuation," filed on April 21, 2011, and WIPO Publication No. WO/2011/156408, titled "Plasma Inducted Fluid Mixing," filed on July 6, 2011. Each of these documents is incorporated by reference herein in its entirety. In general, a plasma

actuator may induce the flow of a fluid, such as air or any other type of fluid, due to the electrohydrodynamic (EHD) body force that results from the electric field lines that are generated between electrodes of the plasma actuator.

**[0040]** Referring now to FIG. 1B, the figure shows air flow 110 being released from an illustrative housing device in a linear direction by an induced jet actuator unit 111 (i.e., a linear induced jet actuator unit). The relative position of the induced jet actuators 111 within the housing and the relative positions of intake vents 112 for the induced jet actuators 111 if required by the type of induced jet actuator used to drive the system are shown. In various embodiments, the induced jet actuators 111 and/or or vents may be added by a novel installation process or may be integrated as part of the refrigeration unit during manufacturing. Adding the actuators/vents to a pre-existing unit allows the owners of existing open-case units to save energy without the cost associated with replacing them. Plus, the amount of energy savings can be substantial, given that refrigeration units generally exhibit useful lifetimes of around 15 years. Moreover, retailers need not experience long down times or disruptions during installation, because the device can be installed quickly and unobtrusively. This is particularly important in the case of 24-hour retailer operations. Systems according to the present disclosure can also be made to be quite compact. This can simplify installation by allowing for simple ways to attach the device and other parts required to operate more efficiently. It can also reduce the overall weight of units and size, taking up less space and requiring less structural support for installations.

**[0041]** FIG. 1C shows the inside of an illustrative housing into which the induced jet actuators 120 used for this device fit into custom molded slots that keep the units in place, while making individual units easier to replace in the event of

mechanical failure. For instance, clip-on-type electrical connections 121 between the induced jet actuators aid in making them easier to install and replace, in one embodiment. Therefore, systems according to the present disclosure may be designed with a housing device that opens from the outside for easy access into the interior. Accordingly, in the event of a failure of an individual induced jet actuator, the individual actuator that has failed can be easily replaced without having to replace the entire housing device. As mentioned, wiring for the induced jet actuators may be clip-on-type for easy replacement, installation, or maintenance. Wiring then may flow into an external power converter whose purpose is to manage the specific power needs of the overall device and which may plug directly into a standard electric outlet, which would make the system "plug and play." This does not eliminate the possibility that a device could be tied into other electrical sources.

**[0042]** FIG. 1D and FIG. 1E show respective front and side views of an illustrative housing unit 123 designed to have an open face where the replacement induced jet actuators 122 can be easily installed or removed. This design reduces maintenance issues and complexity by offering open case refrigeration owners replacement induced jet actuator consumable "cartridges" that are easy to replace and are low cost. A mounting plate 124 is shown and may be used to attach the housing unit 123 to a refrigeration unit.

**[0043]** FIG. 2A shows an illustrative main housing unit 200 for the induced jet actuators and wiring. A flexible door 201 is shown that seals and protects the induced jet actuators and wiring from exposure, while providing easy access to maintain or replace interior components. The opening is positioned away from the interior of the refrigeration device for easy access. A mounting plate 202 is shown,

which can vary in shape, look, and design depending upon the refrigeration unit to which it is attached. A mounting plate can be easily attached to the main housing 200 and is fitted with a separate hinge 203 which is designed to allow the housing unit 200 to be angled in the desired direction of the air flow in accordance with an embodiment of the present disclosure. Systems according to the present disclosure may be constructed to be attached to a refrigeration unit using different customizable attachment types, such as hooks, hinges, glues, bolts, hook-and-loop fasteners (e.g., Velcro™), etc. that can be easily customized to fit virtually any open refrigeration system on the global market today or in the future. The material for the mounting unit may be made of any material or combination, whether natural, glass, stone, metal, plastic, or artificial that may be flexible or inflexible. Accordingly, the mounting plate 202 provides a field-operable customizable mounting mechanism for the housing unit 200, in certain embodiments.

**[0044]** In addition, systems according to the present disclosure may have a pre-manufactured housing device in strips made of any material or combination, whether natural, glass, stone, metal, plastic, or artificial, that may be flexible or inflexible, which may be custom designed to fit the induced jet actuators. Strips may be designed to be angled to match the specific configuration of a refrigeration unit it is being attached to and may be installed in multiple layers vertically or horizontally to meet the specific height or length of the refrigeration unit or to improve performance. Pre-manufactured housing strips may be built to or cut into custom lengths so that a virtual seal can be extended to the sides of refrigeration units in the event that they are open to the ambient air. In one embodiment, a housing strip may have air intake vents built in if required by the specific induced jet actuator being used for a device.

**[0045]** FIG. 2B shows the side elevation of an illustrative housing device 210 and how the angle of a housing unit attached to a mounting plate with a hinge 211 can be rotated in both directions 212 to adjust the direction of the air flow 213 being released by the device. Further, the induced jet actuators, such as plasma actuators may be activated by applying voltages with various types of waveforms across respective electrodes. For example, the plasma actuators may be activated by applying a constant voltage across the respective electrodes. As another example, a sinusoidal voltage may be applied to the plasma actuators. Additionally, each one of the plasma actuators may be individually activated and deactivated according to a predefined pattern.

**[0046]** In an embodiment, the fluid flow induced in a flow passage can be varied by controlling the applied voltage potential, phase angle, and/or frequency across each one of these actuators. In an embodiment, an EHD body force is used to control the flow of a fluid through the flow passage, tunnel, or channel. In an embodiment, a plurality of electrodes are arranged and powered to create a plasma discharge, which can impart an EHD body force to the fluid. Various configurations of electrodes can be used to control the flow of the fluid into, out of, or through the flow passage. In an embodiment, electrodes are arranged at or near the entrance of a channel to draw fluid into the channel. In an embodiment, electrodes are arranged at or near the exit of the channel to draw fluid out of the channel. Various configurations of electrodes can be used.

**[0047]** Next, FIG. 3A shows an illustrative device 300 in its entirety which includes the housing 303 and a mounting plate 304 in accordance with an embodiment of the present disclosure. Air flow creating a waterfall effect 301 is

depicted as it forms a virtual door by separating the ambient air from the internal cold air controlled by the refrigeration unit. In the event that a fairing 302 is required to divert the faster moving air from the interior of the refrigeration unit, it will be attached along the inside or outside bottom portion of the unit. FIG. 3B shows how an illustrative combined device 310 of the housing and mounting plate and if necessary an air diverting fairing 302 could attach to an existing vertically oriented refrigeration unit 311.

**[0048]** Fairings 302 may also be used to assist in directing air inside a refrigerated case if it improves energy efficiency. In certain configurations, air flow will be directed from a higher point in a vertically oriented refrigeration case to a lower point. In horizontal oriented units, a flow of air may be configured to be angled from a lower point to a higher point but away from the direction of potential consumers. Fairings 302 can be made of any material whether natural, glass, stone, metal, plastic, or artificial that can be flexible or inflexible and designed to be easily custom cut to fit the specific system it is being attached to.

**[0049]** FIG. 4A shows an illustrative side elevation of an existing condition of a commonly used vertically oriented refrigeration unit with an "air curtain" 400 of slow moving air. Air loss 401 resulting from the cold air from inside the unit being released into and mixing with the ambient warmer air is shown. In this arrangement, the air curtain utilizes a fan and honeycomb system which releases a very low velocity air flow directed across the unit opening, providing a protective air shield. The air curtain fan adds sufficient kinetic energy to the air, providing the resistance to the penetration of unwanted air or particles. This added kinetic energy in the discharged air is designed to resist the penetration of outside air.

**[0050]** Referring now to FIG. 4B, the figure shows an illustrative side elevation of a relative location where an induced jet actuator's housing 410 could attach to the vertical refrigeration unit 411 in accordance with an embodiment of the present disclosure as part of an upgrade kit. An air diverting device or fairing, if required, could be attached as shown in 412. The wiring from a housing could then plug into an outlet 413 that is separate from the refrigeration unit. Correspondingly, FIG. 4C shows an illustrative housing of induced jet actuators attached to a refrigeration unit 420 and releasing rapid bursts of fast moving air 421 to create the waterfall effect that forms a virtual door that is more difficult for ambient air to penetrate from the outside, while reducing cold air loss from the inside being released into the ambient air. The impact that the air diversion fairing 422 can have on fast moving air away from the interior of the refrigeration unit is shown. In this non-limiting illustration, the waterfall effect provided by the induced jet actuators is used in addition to the air curtain 400 of slower moving air (e.g., provided by a cooling unit and fan & honeycomb assembly (not shown)).

**[0051]** Next, FIG. 5A shows an illustrative side elevation of an existing condition of a commonly used horizontally oriented refrigeration unit 502 with an air curtain 500 of slow moving air (e.g., provided by a cooling unit and fan & honeycomb assembly (not shown)). Air loss 501 resulting from the cold air from inside the unit 502 being released into and mixing with the ambient warmer air is shown. In comparison, FIG. 5B shows an illustrative side elevation of relative locations where the induced jet actuators housing 510 would attach to a horizontally oriented refrigeration unit 511 in accordance with an embodiment of the present disclosure. An air diverting device 512 could be attached as shown (by pointer 513)

if necessary. The wiring from the housing could then plug into an outlet 514 that is separate from the refrigeration unit 511.

**[0052]** Correspondingly, FIG. 5C illustrates a housing of induced jet actuators 520 attached to a refrigeration unit 523, releasing bursts of fast moving air 521 to create the waterfall effect that forms a virtual door which is more difficult for ambient air to penetrate from the outside, and reduces the amount of cold air being released into the ambient air from the inside of the refrigeration unit 523. The impact of the air diversion device or fairing 522 on the fast moving air away from the interior of a refrigeration unit is shown by the redirection of the moving air 521. In this iteration, the air flow is directed from the lower elevation to the higher elevation to keep the air flow away from nearby consumers. In this non-limiting illustration, the waterfall effect 521 provided by the induced jet actuators is used in addition to the air curtain 500 of slower moving air (e.g., provided by an evaporator and fan & nozzle assembly (not shown)).

**[0053]** FIG. 5D illustrates a different embodiment, where the housing of induced jet actuators 520 is positioned so that it pulls cold air from the interior of the unit instead of the exterior ambient warm air. In this embodiment, the air diversion device or fairing 522 is used to bring the air flow 521 back into the interior of the unit to create a rotational effect within the unit that recycles the cold air and reduces the power use of the refrigeration unit 523.

**[0054]** FIG. 6A illustrates a side elevation of two housing units 600 of induced jet actuators attached to a refrigeration unit 602, both releasing faster moving air 601 to form multiple waterfall effects in accordance with an embodiment of the present disclosure. This creates a virtual door that is more difficult for ambient air

to penetrate from the outside and reduces the amount of cold air loss from the inside. This configuration may be contemplated to further improve the performance of the virtual door, particularly on taller vertically oriented units or in more turbulent high traffic consumer environments. Thus, FIG. 6B illustrates a front elevation of two housing units of induced jet actuators attached to a refrigeration unit, both releasing fast moving air 610 to create a multiple waterfall effect that would not be visible from the outside of the unit in accordance with an embodiment of the present disclosure. The overall air flow 611 moving down and away from the refrigeration unit at ground level is depicted. Newly manufactured refrigeration units may be designed and built to include this type of configuration, in some embodiments.

**[0055]** Referring next to FIG. 7, the figure shows a view of a vertically oriented refrigeration unit with housing units of induced jet actuators 700 attached in accordance with an embodiment of the present disclosure. The figure shows the air flows 701 being moved downward and away from a refrigeration unit at the front facing part of the unit and the side facing part or panel of the unit. Accordingly, waterfalls of fast moving air may be created at both the side(s) and in front of the refrigeration unit in some embodiments. Further, as discussed below, a tunnel of fast moving air may also be created at a rear or back panel of the refrigeration unit. Additionally, FIG. 8A shows an illustrative front elevation of a refrigeration unit and the effect a penetrating arm 800 (e.g., human arm or other object) would have on the air flow that is being released in a waterfall effect manner. The faster moving air from the induced jet actuators could move air flow around 801 the penetrating object and eventually "re-seal" behind that object 802. For embodiments of the present disclosure, induced jet actuators in a linear actuator unit may be sized to

create a flow that is sufficient to reduce energy losses through the open face by an amount that exceeds a total power requirement for the linear jet actuator units.

**[0056]** FIG. 8B shows a perspective view of a refrigeration unit 810 with a door 811 to illustrate the forces that create cold air loss when the door 811 is opened. Correspondingly, FIG. 8C shows a top view. As the door 811 is opened (as indicated by pointer 812) and the refrigeration seal is broken, the cold air 813 is pulled out the entire surface area of the door 811, as compared to the opening 801 in FIG. 8 where the air loss is limited to the object that breaks the plane of the air flow. The cold air 813 that is pulled out of the refrigeration unit then immediately creates a vacuum, which is filled with warm ambient air rushing in to fill the void.

**[0057]** Next, FIG. 9A shows the state of the art usage of a cold air curtain in a typical vertically open refrigeration unit or display case (ORDC). The case includes a product holding volume for holding one or more products and defines at least one open face through which the product holding volume can be accessed. The case may also hold a plurality of shelves, where the opening may then span the plurality of shelves to define a multi-level product volume behind the open face.

**[0058]** Generally, in an open refrigeration unit or display 900, a cooling unit, such as an evaporator, 901 is used to cool the air it receives and then distribute the cooled air up the back plate or panel and across the opening of the refrigeration unit. The cooled air may also diffuse through the back panel 902 to the interior of the unit 900. Correspondingly, air 903 from the interior of the unit 900 may diffuse through the back panel 902 without being properly received by the evaporator 901 and may be returned to the interior of the unit 900 via an air curtain inlet 904 at an elevated temperature. As depicted in FIG. 10, one recent study (from Gaspar, et al.

in Applied Thermal Engineering, 31 (2011) 961-969) has shown that as much as 75% of the energy consumption of an open refrigeration unit is caused by the cold air leakage from the open space and the penetration of the warmer ambient air into the refrigeration unit.

**[0059]** Accordingly, a better prevention of this loss will come from a better flow design. As shown in FIG. 9B, single air curtain 905 and a faster moving waterfall effect of air flow 906 jointly may be used to provide improved performance and cooling loss at the front of a refrigeration unit 907. Either one or both of the air curtain 905 and waterfall effect 906 may include a honeycomb structure for directing flow of air. However, cool air from the interior may escape via diffusion through the back panel 908. While many studies have been performed in this area, none showed significant gain in energy efficiency to change the state of the art in a disruptive fashion.

**[0060]** Accordingly, one embodiment of a new design for improved energy efficiency utilizes induced jet actuators (e.g., plasma actuators, synthetic jet actuators, etc.) for redirecting cold air by momentum induced by the induced jet actuators near a back plate or panel of a refrigeration unit. FIG. 11 shows a refrigeration unit 1100 having an evaporator 1101 that is used to cool the air it receives and then distribute the cooled air up the back plate or panel 1102 and across the opening of the refrigeration unit 1100 via an inner air curtain inlet 1103 (inner air curtain) and an optional outer air curtain inlet 1104 (outer air curtain). Either one or both of the inlets 1103, 1104 may include a honeycomb structure for directing flow of air in the air curtain(s). Further, the back panel 1102 is fitted with induced jet actuator(s) P, and it is noted that the following solution is beneficial for porous or non-porous types of back panels 1102.

**[0061]** As a non-limiting example, the induced jet actuators may consist of plasma actuators P and a narrow plasma tunnel may be created by the plasma actuator(s) P inducing cold air recirculation (including air flow received through the back panel, if applicable) and reducing cold flow leakage through the back panel 1102. Although the direction of the flow of air created by plasma actuators P (or induced jet actuators, in general) is shown to be upwards in the figure, the flow of air may also be in other directions, such as downwards, in certain embodiments.

**[0062]** Such a new configuration of actuators P in a plasma tunnel reduces heat loss in open refrigeration units by locating them in the rear of the case/unit. This saves the energy loss in the following manner. First, the flow leakage from the back plate 1102 of the refrigeration unit 1100 is partially or fully eliminated. Second, the cold air injected in the front is entrained in reducing hot air infiltration through the open window of the refrigeration unit 1100. Advantages of the new plasma augmented ORDC include (1) nearly (60%) less energy consumption for the cooling fan system due to reduced flow leakage, (2) better cooling management due to local cold fluid recirculation and less warm air entrainment, and (3) fresher produce due to ozonation (e.g., ozone is capable of being produced by plasma actuators P). One of the advantages of this embodiment is that it can be implemented as a retrofit solution to existing systems along with the other embodiments encompassing the front openings of open case refrigeration units.

**[0063]** Embodiments of the present disclosure additionally include a method of providing an airflow effect formed from induced jet actuator(s) for use with an open-front refrigerated display case. The method includes providing an open-front refrigerated display case configured to refrigerate or chill products contained within an interior volume of the display case and providing a first flow path that creates a

layer of air across an open front of the case comprising bursts of fast moving air formed from one or more induced jet actuators. The method may also include providing a second flow path within a rear of the open-front refrigerated display case that circulates a layer of air across the rear of the case comprising bursts of fast moving air formed from one or more induced jet actuators.

**[0064]** Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the present disclosure. As a non-limiting example, induced jet actuators may be positioned at or near a back of a refrigeration unit (e.g., induced jet actuators P) in addition with induced jet actuator(s) 1201 and optional fairing(s) 1202 positioned at or near a front of the refrigeration unit, as shown in FIG. 12. As stated with FIG. 11, the induced jet actuators create a narrow plasma tunnel inducing cold air recirculation (including air flow received through the back panel, if applicable) and reducing cold flow leakage through the back panel 1102. Although the direction of the flow of air created by plasma actuators P (or induced jet actuators, in general) is shown to be upwards in the figure, the flow of air may also be in other directions, such as downwards, in certain embodiments.

**[0065]** Next, FIG. 13 shows an illustrative state of the art refrigeration unit 1300 with embodiments of the induced jet actuator units 1301, P integrated into the refrigeration unit. Accordingly, the induced jet actuator units 1301, P may be included as part of a newly manufactured open case refrigeration unit 1300. As a system with induced jet actuators integrated into the system, various other design elements may also be included. For example, a state of the art air curtain using a honeycomb filter is shown by pointer 1103, where the air flow from the air curtain is contained using the induced jet actuator 1301 of the present disclosure. The air is

then captured at the bottom of the unit (as indicated by pointer 1304), where the cold air is recycled thorough the unit where it is chilled by a cooling unit 1101.

**[0066]** In certain embodiments, induced jet actuators 1306 are installed in lieu of inefficient fans which are currently state of the art (as indicated by pointer 1305). For maintenance and replacement of consumable parts, such as induced jet actuators in cartridge form, a door 306 has been added as an easy access point in the front of the unit in some embodiments. To manage the ozone, filters 1303 may be used. Thus, door access panel 1302 is provided, in some embodiments, for easy access to the ozone filters 1303 (and air flow equipment) without requiring the refrigeration unit 1300 to be moved. Alternatively to using filters, catalysts (not shown) or other ozone management devices may be used in or along the unit's air flow areas for ozone management. Such a system could generate substantial savings for end users of open case refrigeration units by efficiently recycling the cold air (as indicated by pointer 1307) and reducing the power use of the refrigeration unit 1300. Further, the ease of integration of induced jet actuator units of the present disclosure could fundamentally change the performance expectations of these units worldwide saving energy on a global scale.

**[0067]** It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the present disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

## CLAIMS

Therefore, at least the following is claimed:

1. An open refrigeration apparatus, comprising:

a case that includes a product holding volume for holding one or more products and defines at least one open face through which the product holding volume can be accessed,

a cooling unit to cool the product holding volume in the case, and

a first induced jet actuator unit having one or more air outflow vents positioned with respect to the case to create a flow of air from the air outflow vents at least generally parallel to the open face to separate the product holding volume from an ambient volume outside of the case.

2. The apparatus of claim 1, wherein the first induced jet actuator unit is operative to cause a succession of bursts of air to form the flow of air from the air outflow vents.

3. The apparatus of claim 1, wherein the first induced jet actuator unit comprises one or more plasma actuators that operate to produce the flow of air independently of any mechanically linked moving parts.

4. The apparatus of claim 1, wherein the first induced jet actuator unit operates to produce the flow of air by deformation of a plurality of pumping elements.

5. The apparatus of claim 1, wherein the first induced jet actuator unit comprises one or more synthetic jet actuators.

6. The apparatus of claim 1, wherein the first induced jet actuator unit includes a plurality of linear induced jet actuators housed in a linear induced jet actuator housing that further includes a mounting mechanism.

7. The apparatus of claim 1, wherein the case holds a plurality of shelves and wherein the opening spans the plurality of shelves to define a multi-level product volume behind the open face.

8. The apparatus of claim 1, wherein the open refrigeration apparatus further includes an air curtain unit to produce an air curtain located between the product holding volume and the flow of air from the first induced jet actuator unit and wherein the air curtain operates at an air speed that is lower than an air speed of the flow of air from the jet actuator.

9. The apparatus of claim 1, wherein the induced jet actuators in the first induced jet actuator unit are sized to create the flow of air which is sufficient to reduce energy losses through the open face by an amount that exceeds a total power requirement for the first induced jet actuator unit.

10. The apparatus of claim 1, wherein the first induced jet actuator unit is formed integrally with the case.

11. The apparatus of claim 1, further comprising a second induced jet actuator unit having one or more air outflow vents located at a rear of the case for circulating air from throughout an interior of the case and prohibiting the air from traveling from the interior through a back panel of the case.

12. The apparatus of claim 11, wherein the second induced jet actuator unit is operative to fully eliminate flow leakage through the back panel.

13. The apparatus of claim 11, wherein the second induced jet actuator unit is operative to partially eliminate flow leakage through the back panel.

14. The apparatus of claim 11, wherein the second induced jet actuator unit is formed integrally with the case.

15. The apparatus of claim 11, further comprising a third induced jet actuator unit that aids in recirculation of air through a channel within the case, the case further including a door access panel allowing access to the third induced jet actuator unit.

16. The apparatus of claim 15, further comprising an additional door panel that allows access to an ozone management device location within the case.

17. The apparatus of claim 16, further comprising the ozone management device, wherein the ozone management device comprises an ozone filter or ozone catalyst device.

18. The apparatus of claim 1, wherein the first induced jet actuator unit comprises one or more individual induced actuators housed in replaceable cartridges.

19. An open refrigeration unit upgrade kit, comprising:

one or more induced jet actuator units that each include one or more induced jet actuators housed in an induced jet actuator housing and having one or more air outflow vents; and

a field-operable customizable mounting mechanism on the induced jet actuator unit constructed and adapted to be mounted with respect to an open face of an open refrigeration unit through which products can be accessed and to create a flow of air from the air outflow vents at least generally parallel to the open face.

20. The open refrigeration unit upgrade kit of claim 19, wherein the one or more induced jet actuators in the induced jet actuator units are sized and set to create the flow of air which is sufficient to reduce energy losses through the open face by an amount that exceeds a total power requirement for the one or more induced jet actuator units.

21. The open refrigeration unit upgrade kit of claim 19, further comprising a field-operable customizable mounting mechanism on the induced jet actuator unit constructed and adapted to be mounted with respect to a back panel of the open refrigeration unit to create a flow of air from the one or more air outflow vents at least generally parallel to the back panel.

22. The open refrigeration unit upgrade kit of claim 19, wherein the one or more induced jet actuators comprise a plurality of plasma actuators that operate to produce the flow of air independently of any mechanically linked moving parts.

23. The open refrigeration unit upgrade kit of claim 19, wherein the one or more induced jet actuators comprise a plurality of synthetic jet actuators.

24. An open refrigeration unit upgrade method for an open refrigeration unit, comprising:

positioning a first induced jet actuator unit having an air intake vent and one or more air outflow vents so that the first induced jet actuator unit is positioned with respect to the open refrigeration unit to create a flow of air from the one or more air outflow vents at least generally parallel to an open face of the open refrigeration unit; and

attaching the positioned first induced jet actuator unit to the open refrigeration unit using a field-operable mounting mechanism for the first induced jet actuator unit.

25. The method of claim 24, wherein the flow of air created by the first induced jet actuator moves upwards with respect to a positioning of the first induced jet actuator on the refrigeration unit.

26. The method of claim 24, wherein the flow of air created by the first induced jet actuator moves downwards with respect to a positioning of the first induced jet actuator on the refrigeration unit.

27. The method of claim 24, wherein the first induced jet actuator unit is positioned between an air curtain of moving air that is slower than the flow of air created by the first induced jet actuator unit and ambient air external to the open refrigeration unit.

28. The method of claim 24, further comprising:

positioning a second induced jet actuator unit having an air intake vent and one or more air outflow vents so that the second induced jet actuator unit is positioned with respect to the open refrigeration unit to create a flow of air from the one or more air outflow vents at least generally parallel to a back panel of the open refrigeration unit; and

attaching the positioned second induced jet actuator unit to the back panel of the open refrigeration unit using a field-operable customizable mounting mechanism for the second induced jet actuator unit.

29. The method of claim 28, wherein the flow of air created by the second induced jet actuator moves upwards with respect to a positioning of the second induced jet actuator on the refrigeration unit.

30. The method of claim 28, wherein the flow of air created by the second induced jet actuator moves downwards with respect to a positioning of the second induced jet actuator on the refrigeration unit.

31. The method of claim 28, wherein the second induced jet actuator unit is operative to fully eliminate flow leakage from the back panel.

32. The method of claim 24, further comprising:

positioning a third induced jet actuator unit having an air intake vent and one or more air outflow vents so that the third induced jet actuator unit is positioned with respect to the open refrigeration unit to create a flow of air from the one or more air outflow vents at least generally parallel to a side panel of the open refrigeration unit that is adjacent to the back panel and front opening; and

attaching the positioned third induced jet actuator unit to the side panel of the open refrigeration unit using a field-operable customizable mounting mechanism for the third induced jet actuator unit.

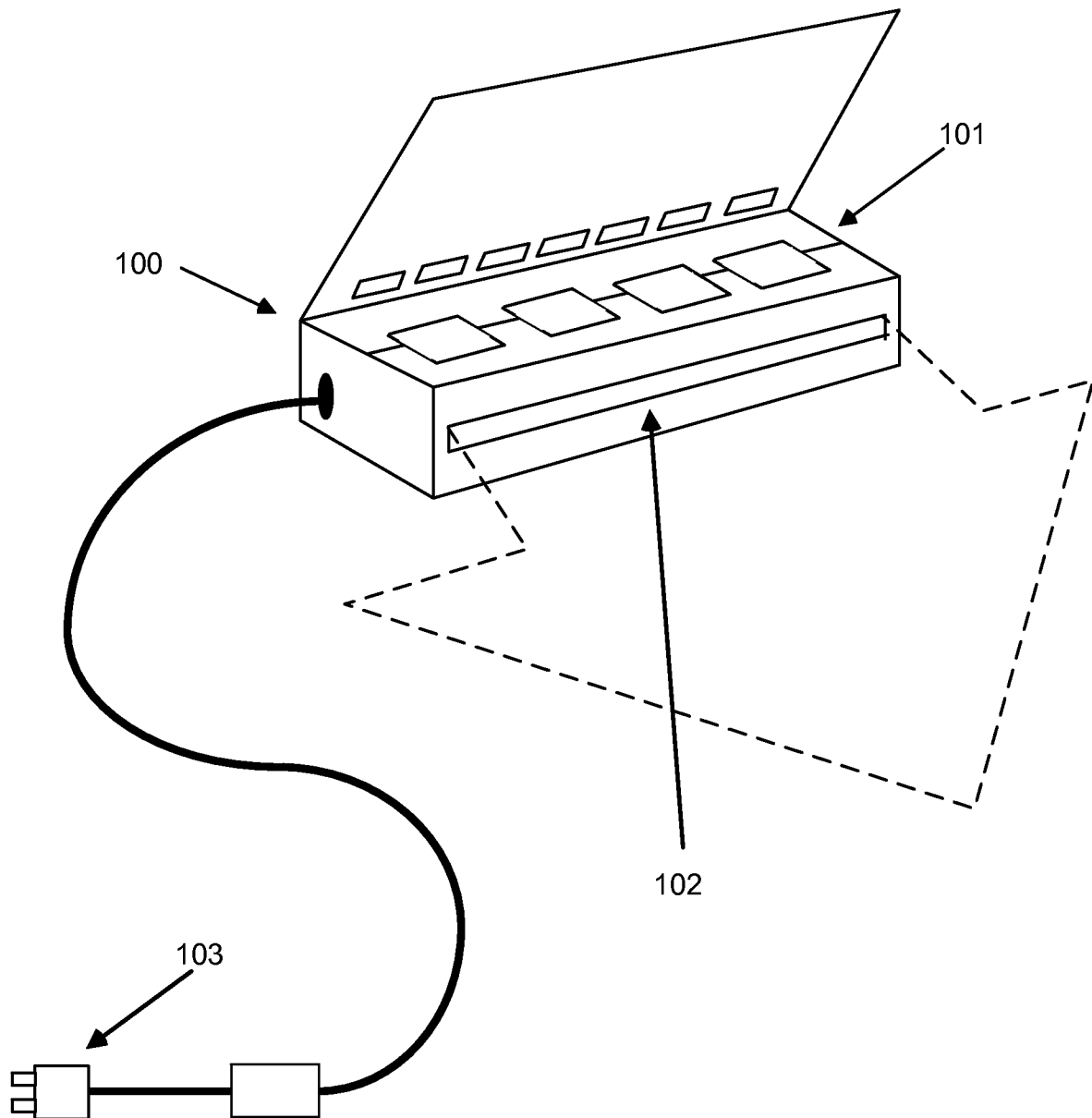


FIG. 1A

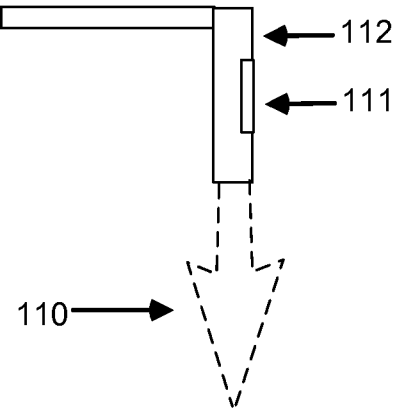


FIG. 1B

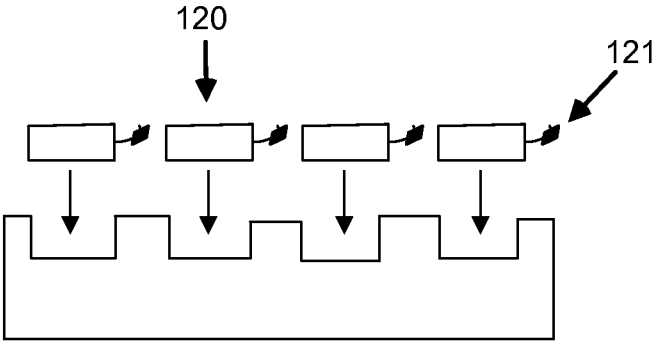


FIG. 1C

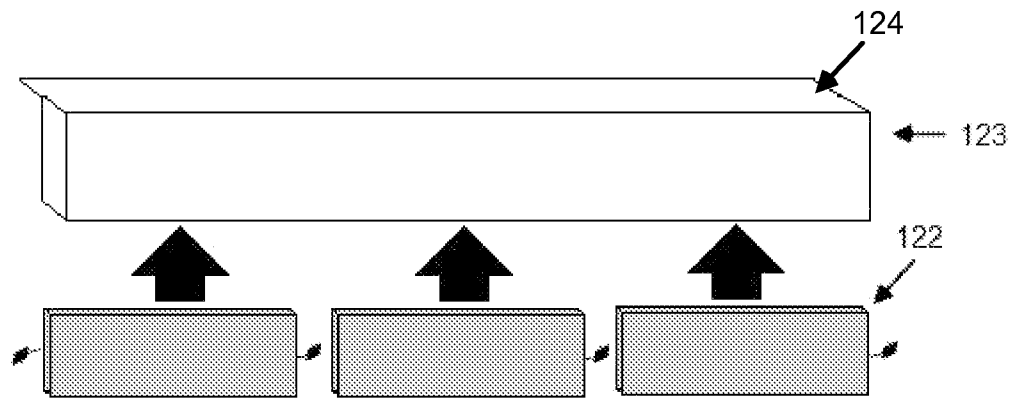


FIG. 1D

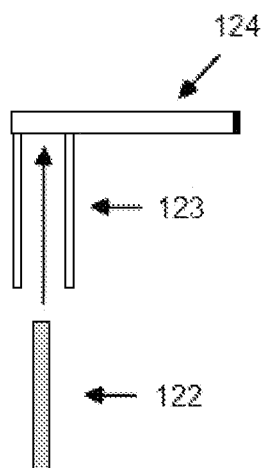


FIG. 1E

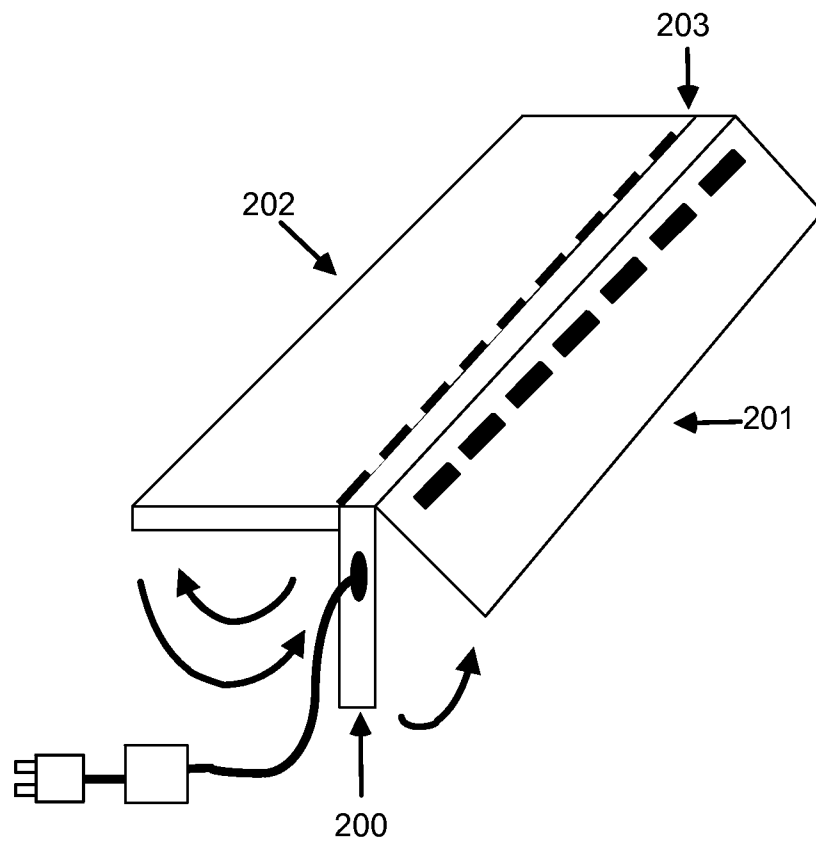


FIG. 2A

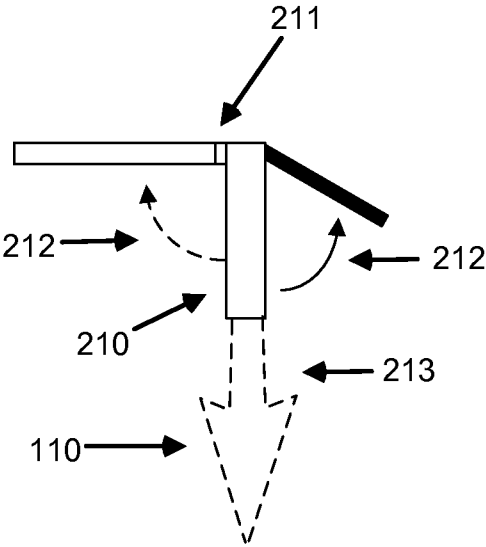


FIG. 2B

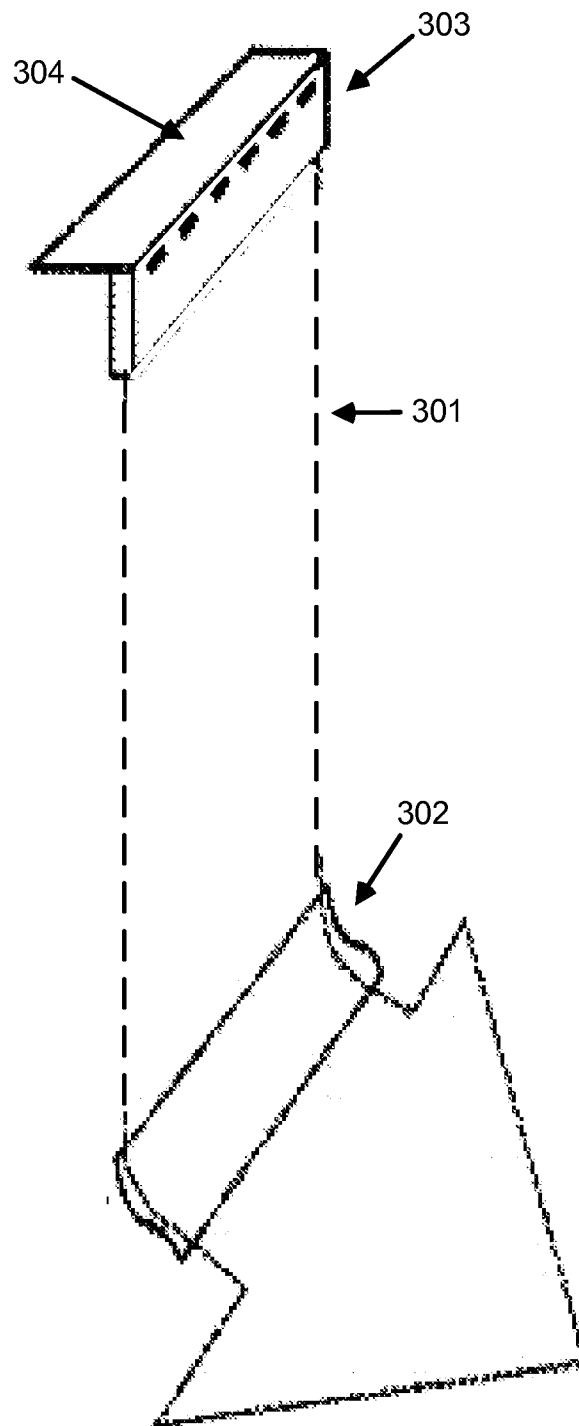


FIG. 3A

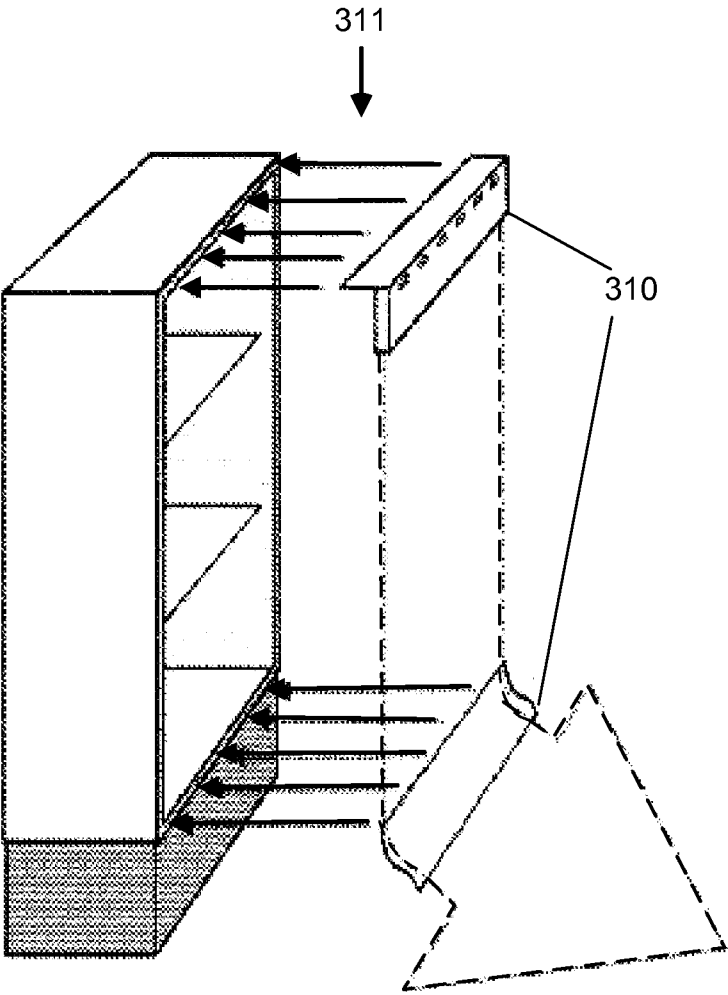


FIG. 3B

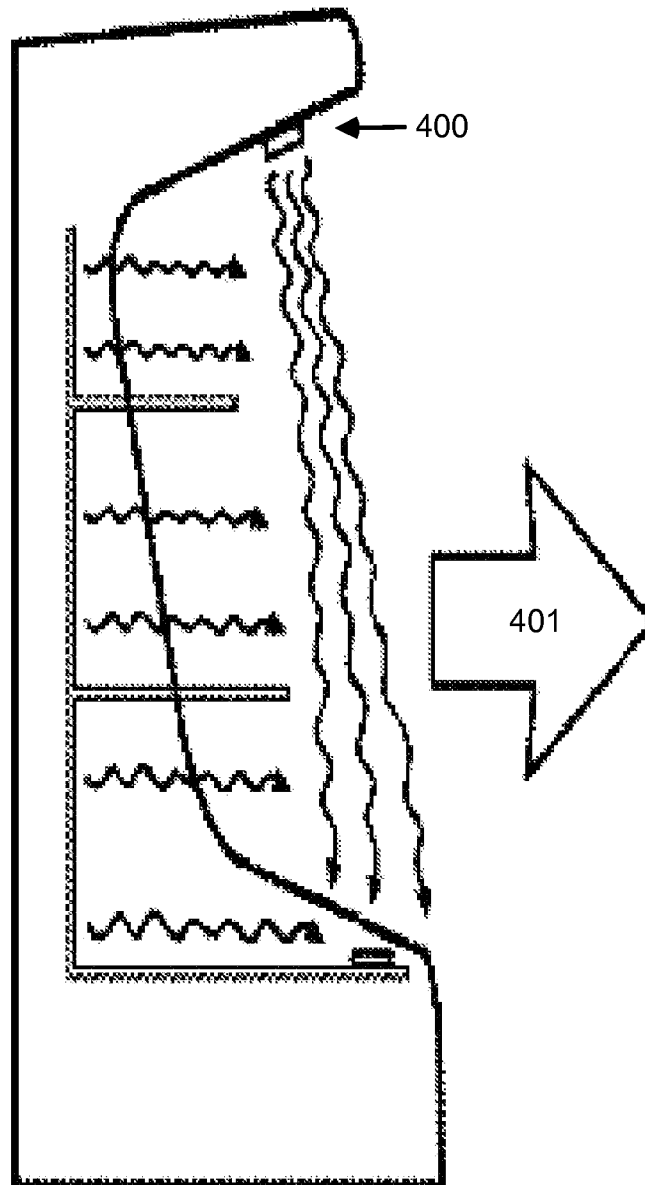


FIG. 4A

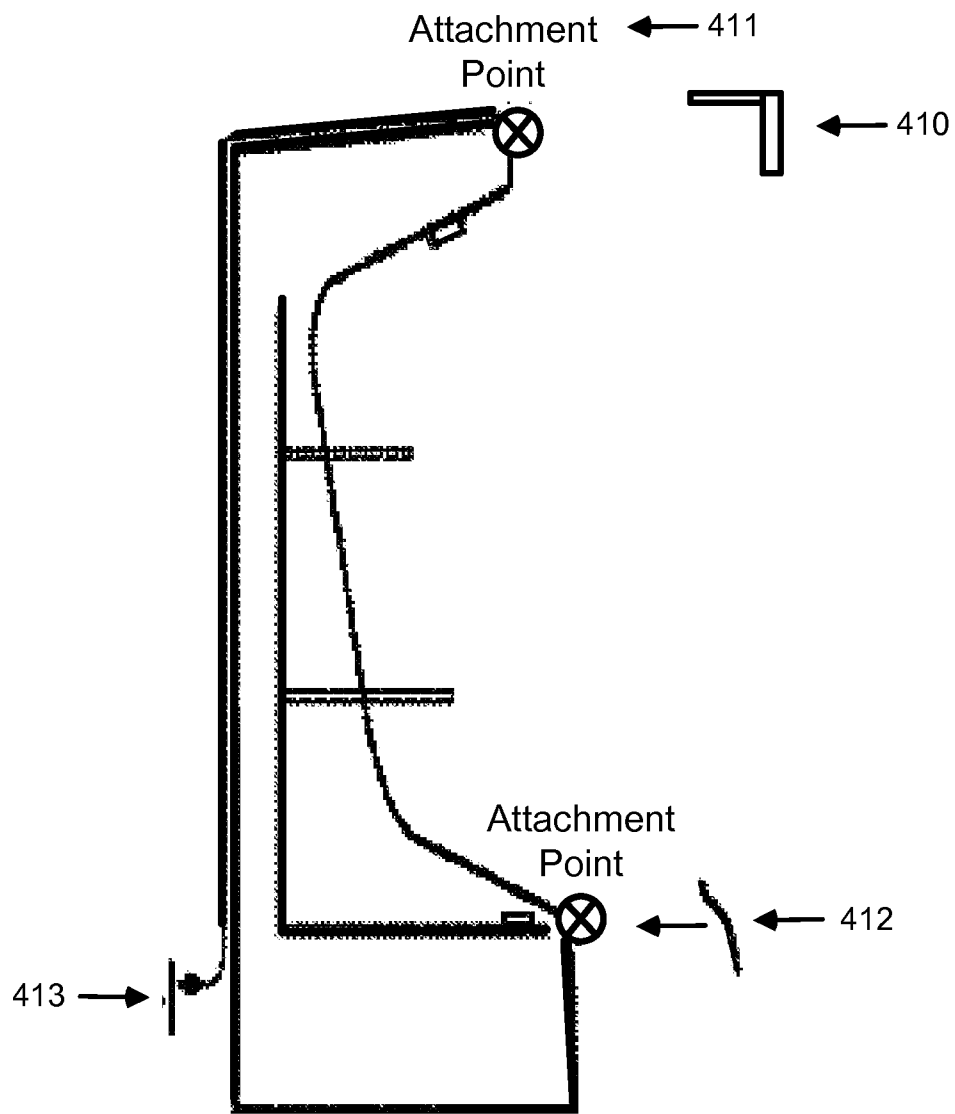


FIG. 4B

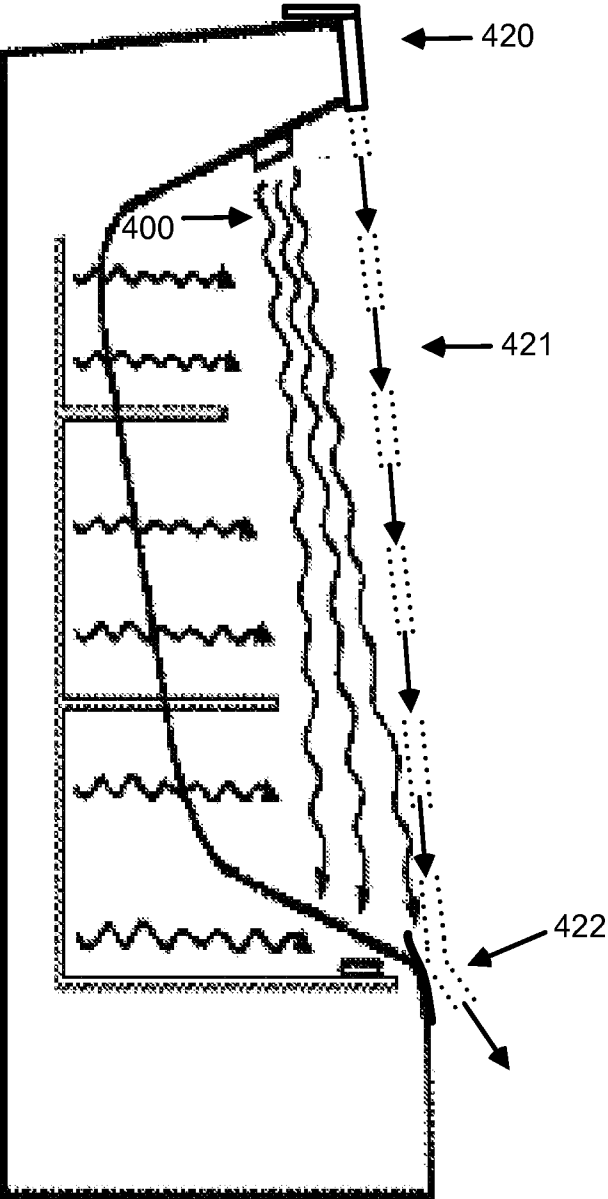


FIG. 4C

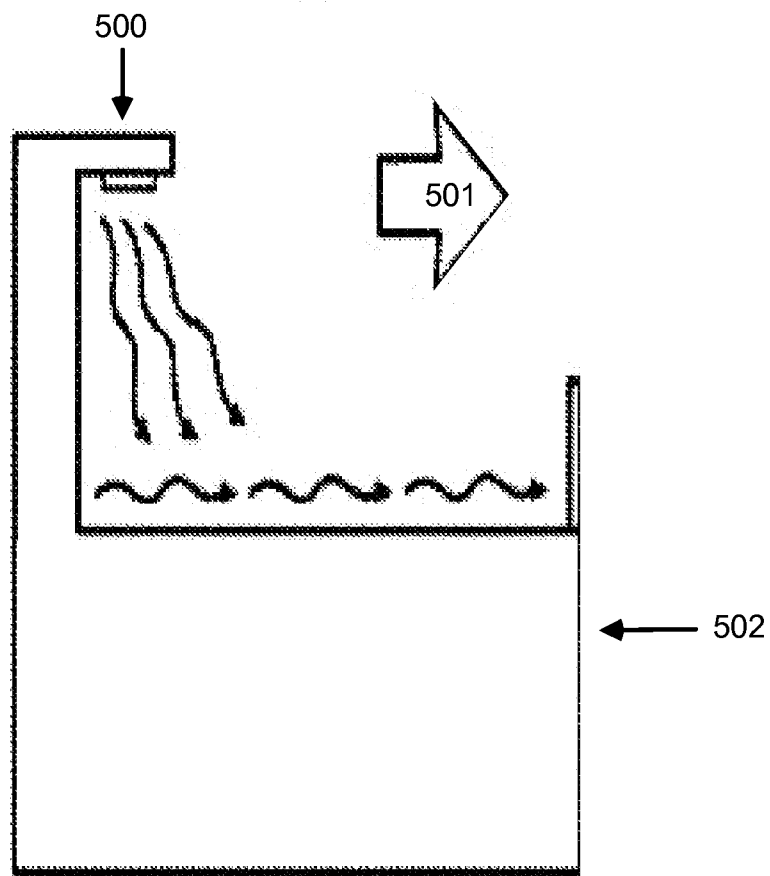


FIG. 5A

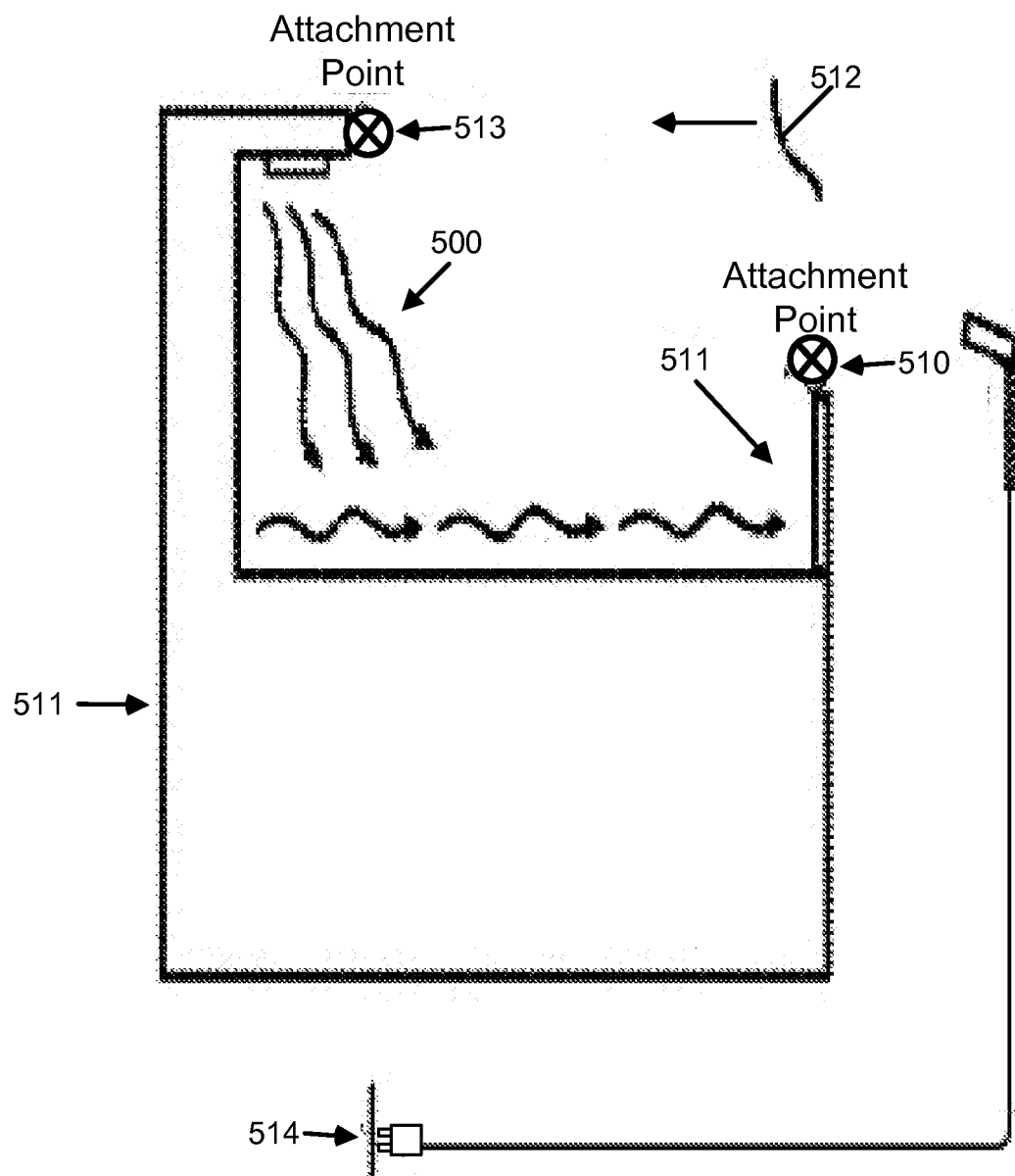


FIG. 5B

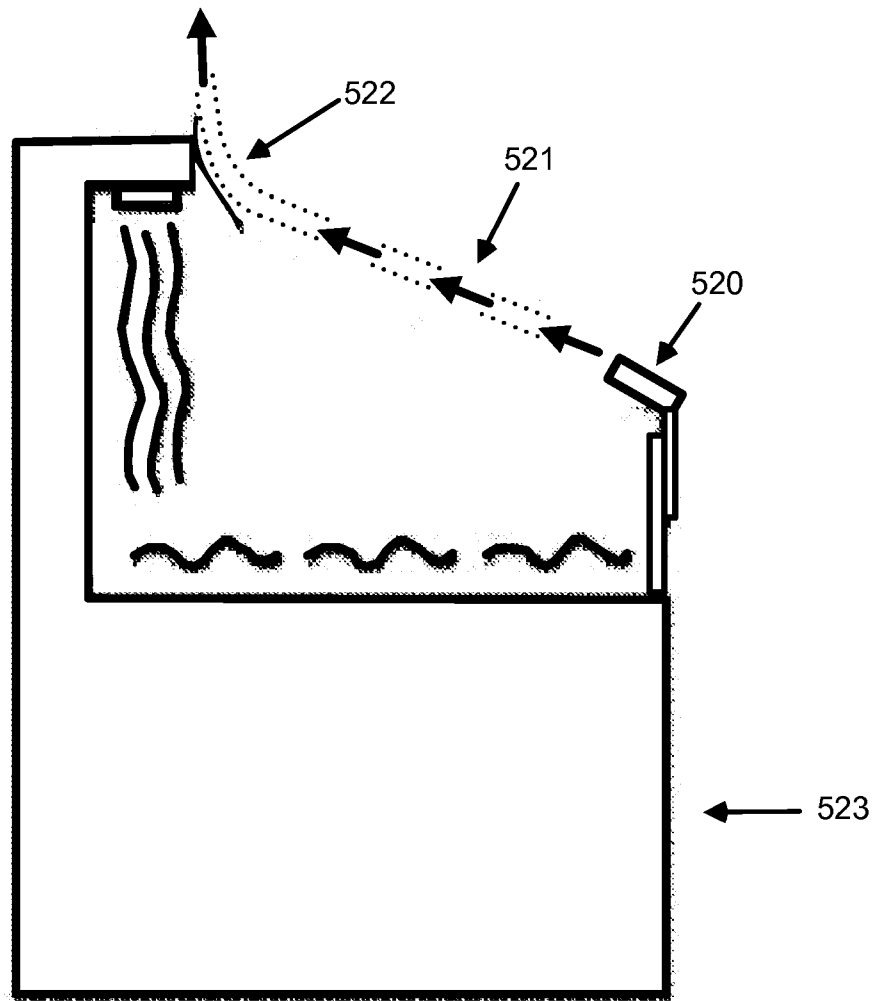


FIG. 5C

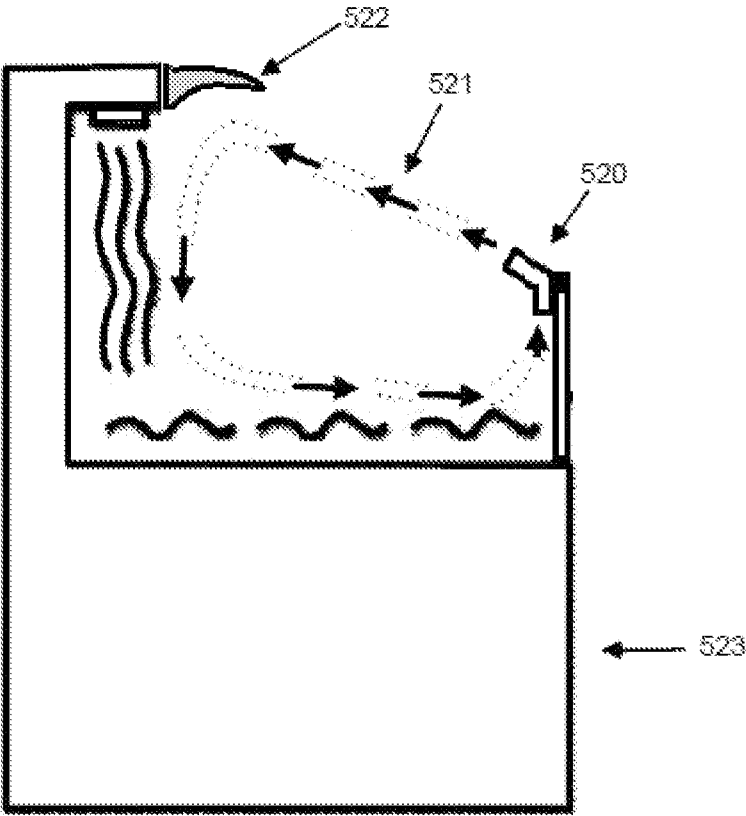


FIG. 5D

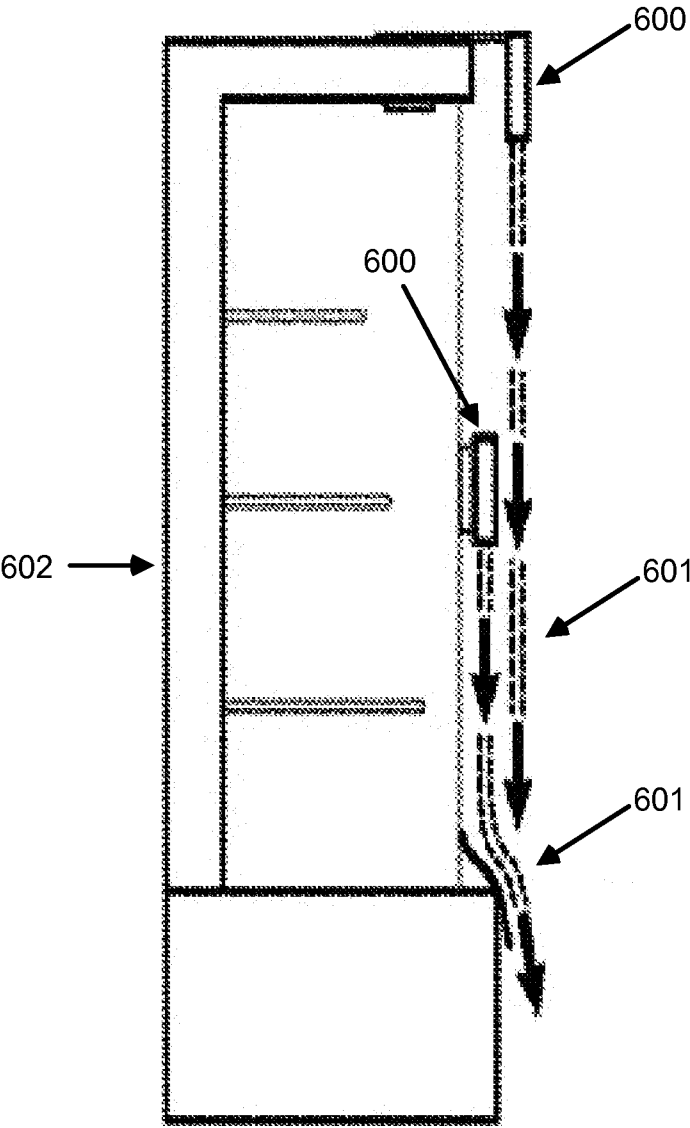


FIG. 6A

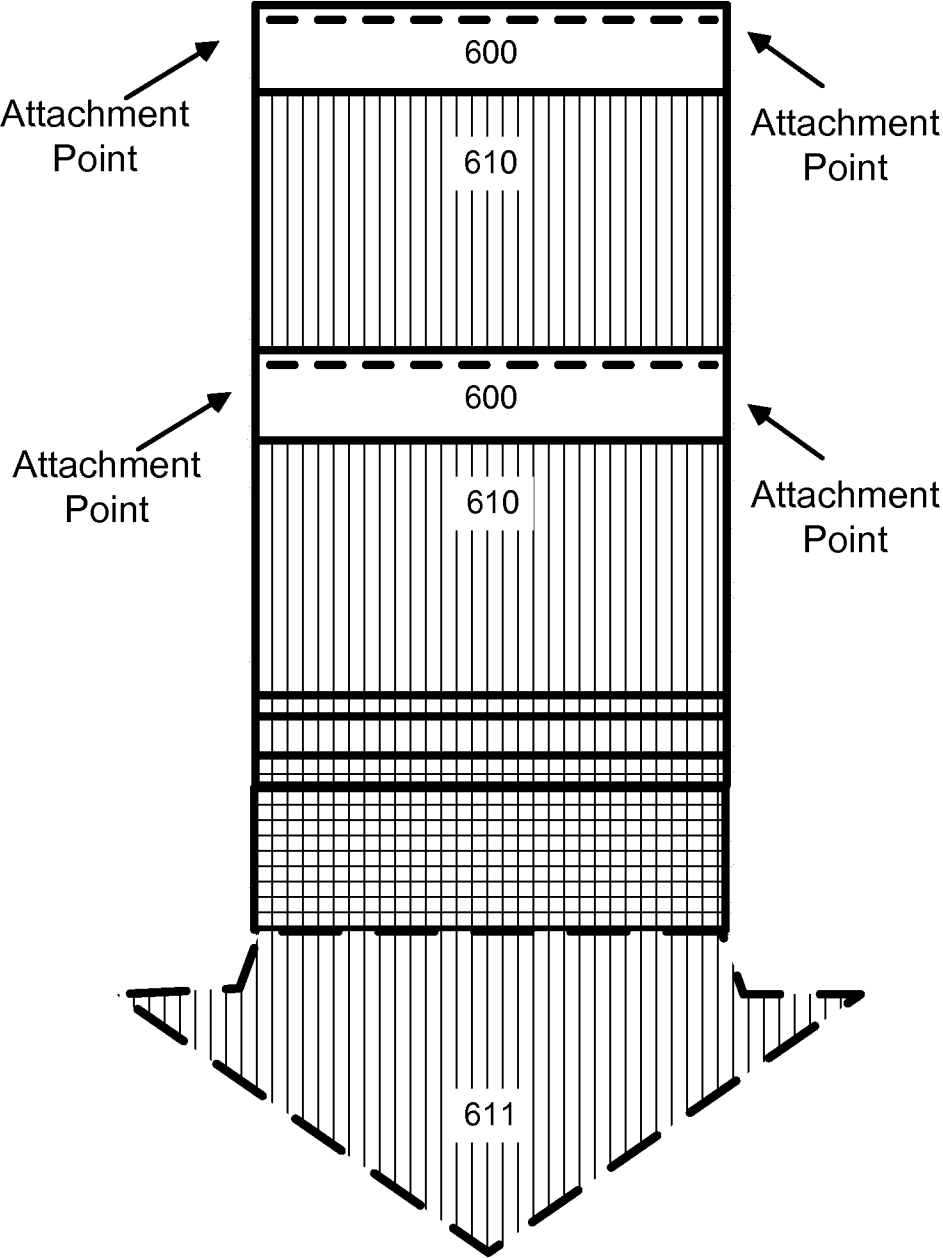


FIG. 6B

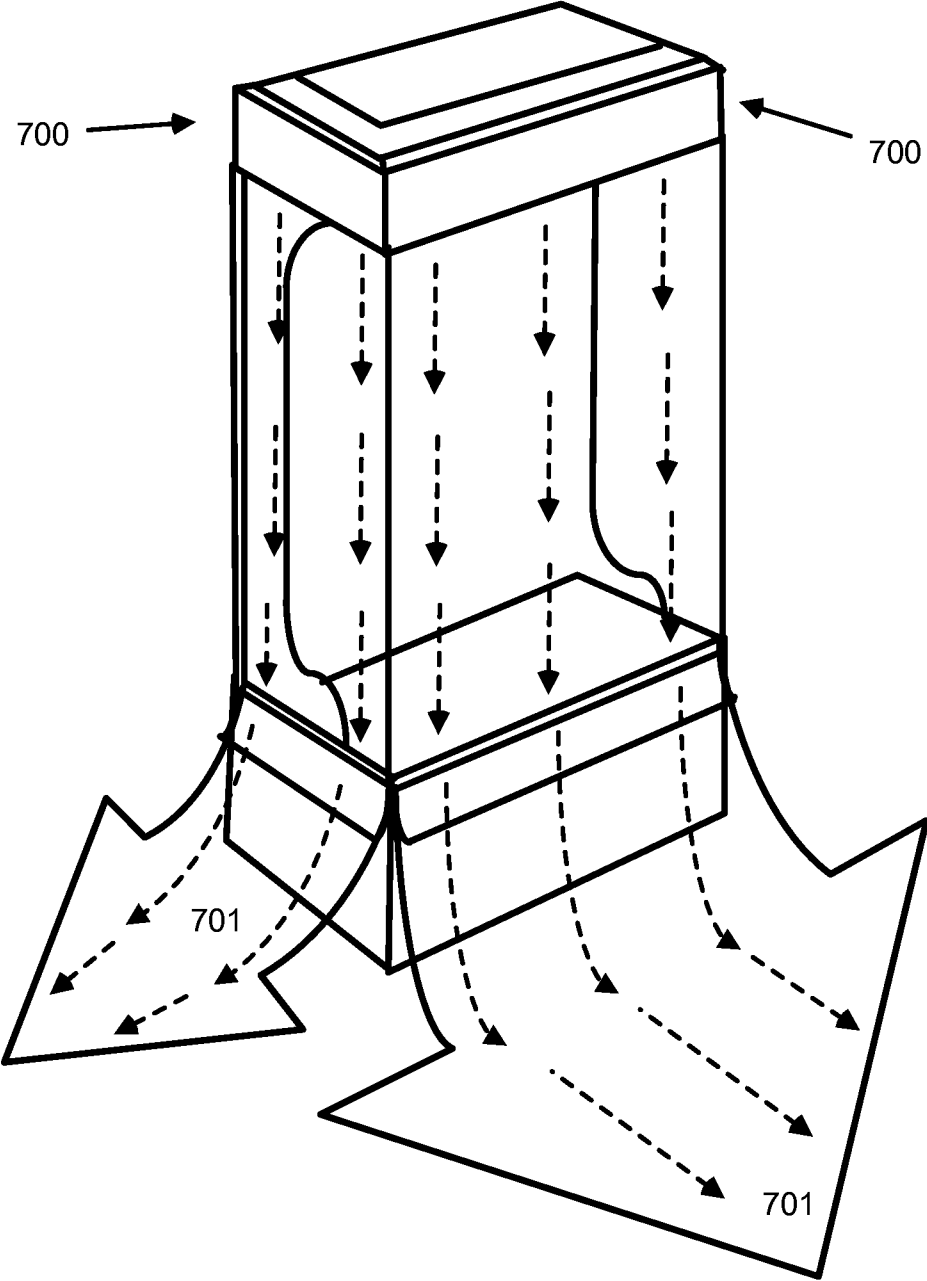


FIG. 7

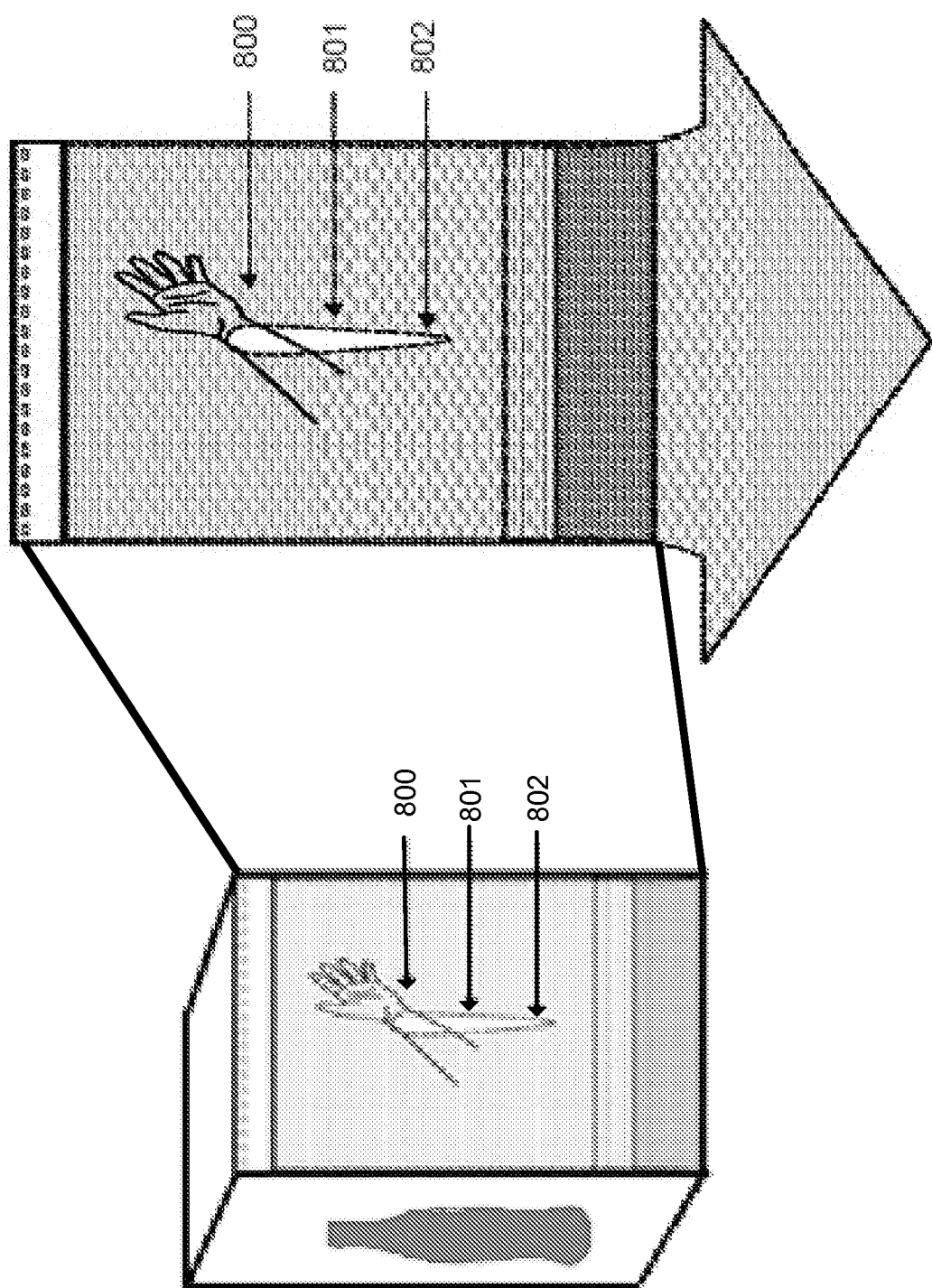


FIG. 8A

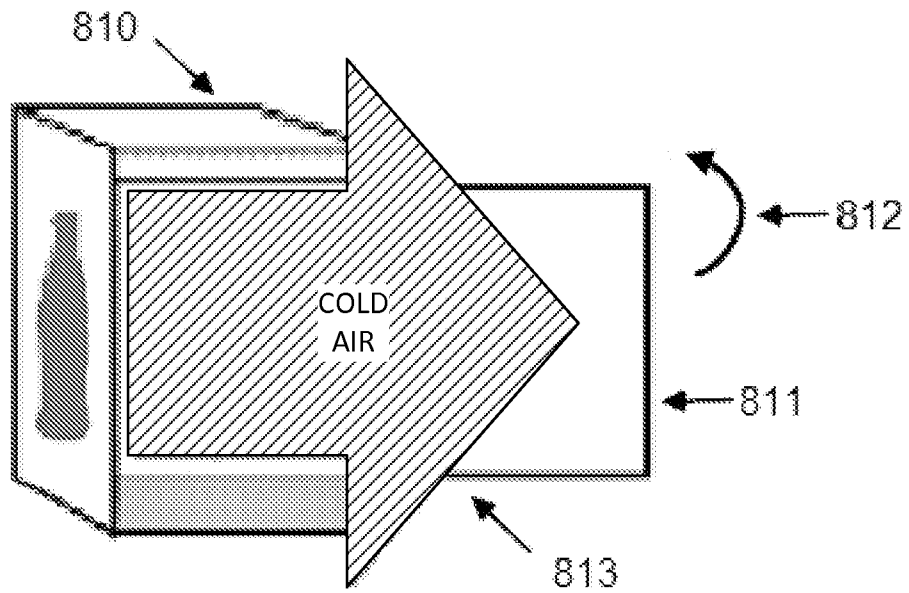


FIG. 8B

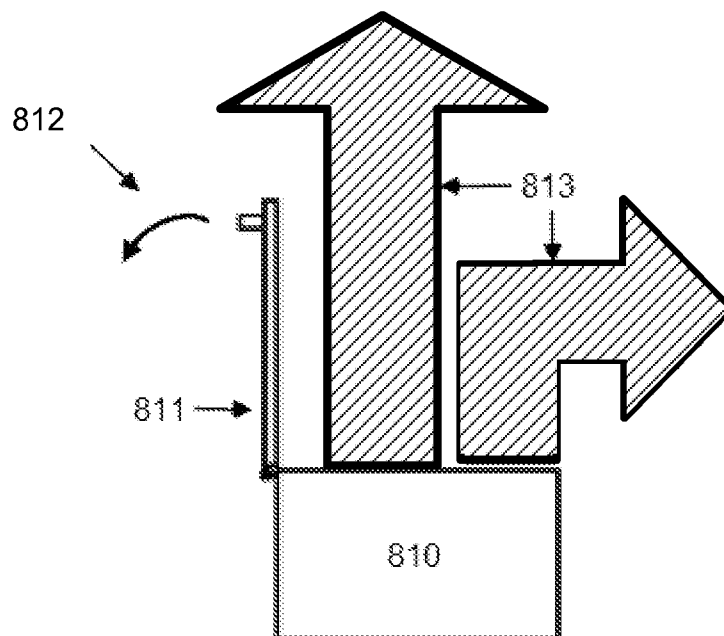
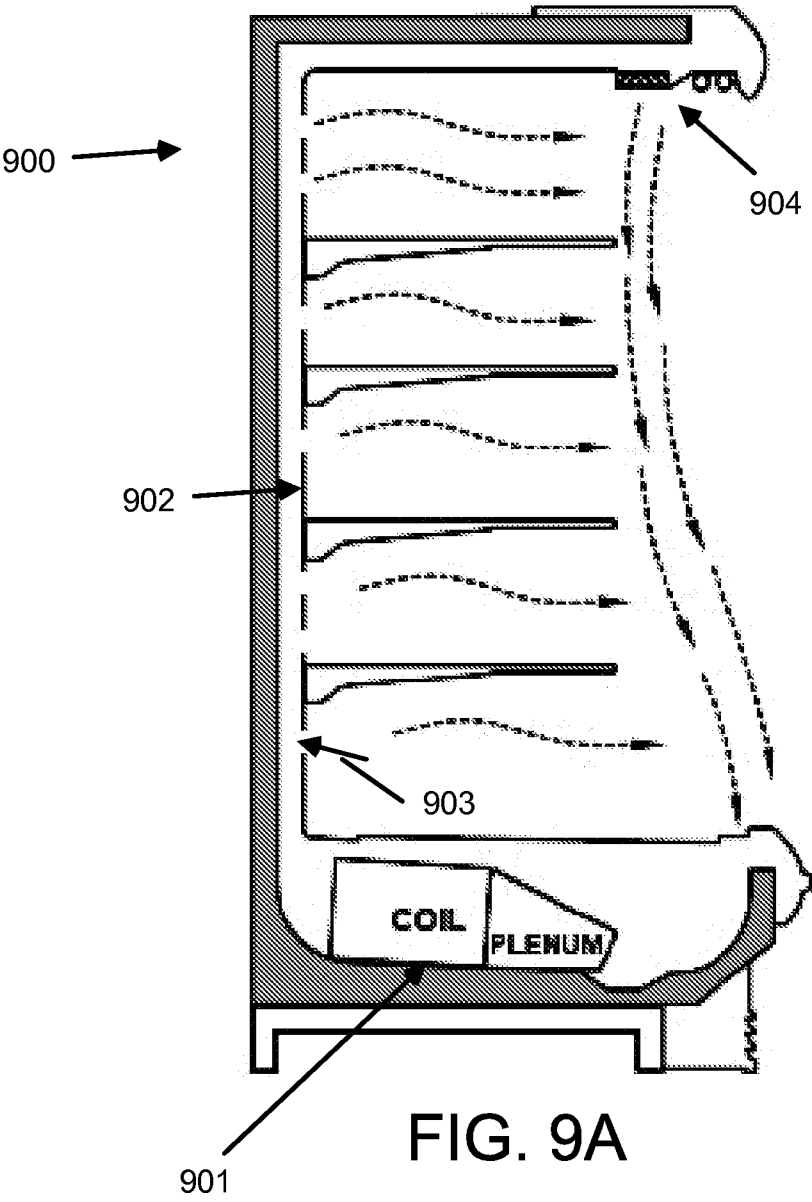


FIG. 8C



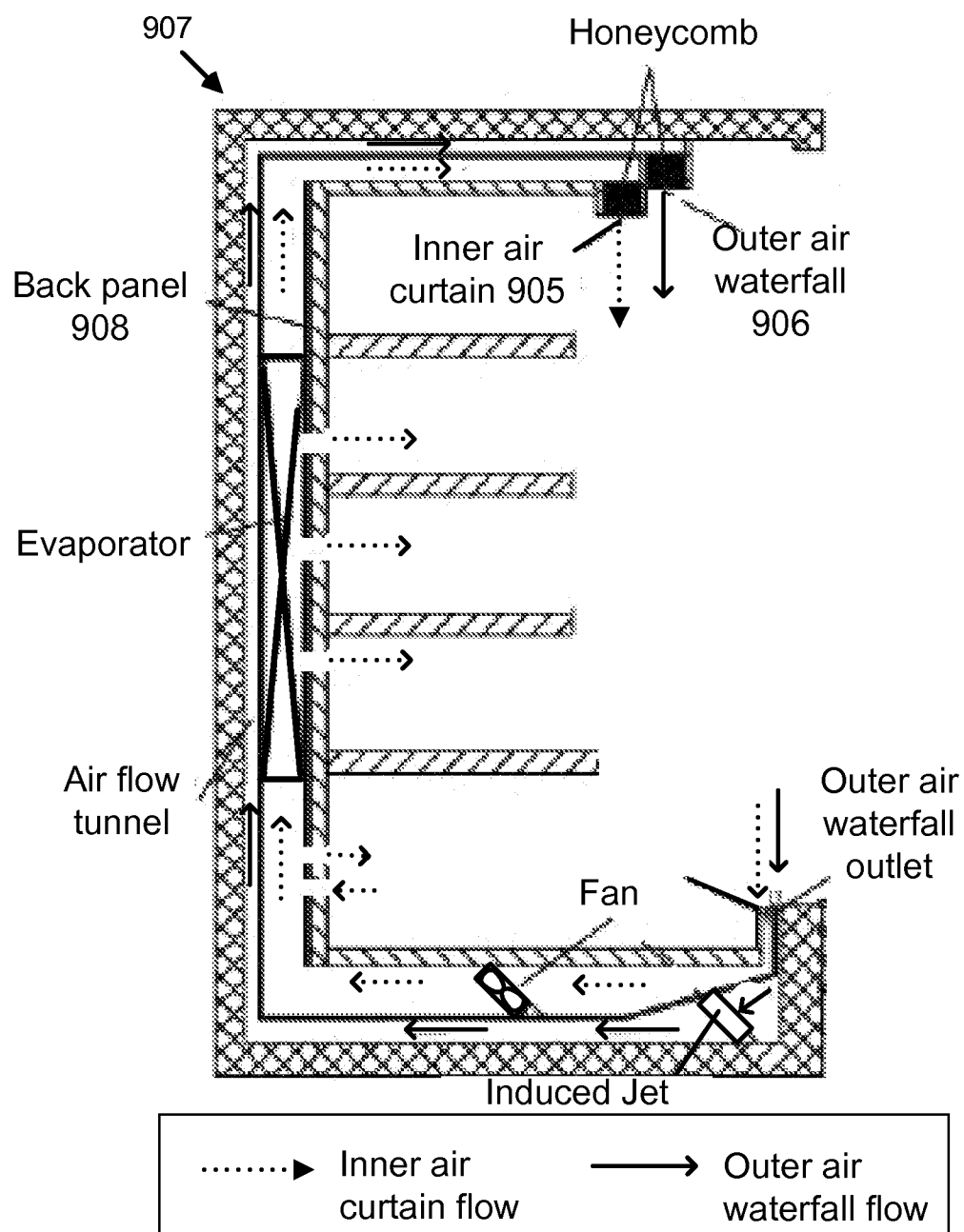


FIG. 9B

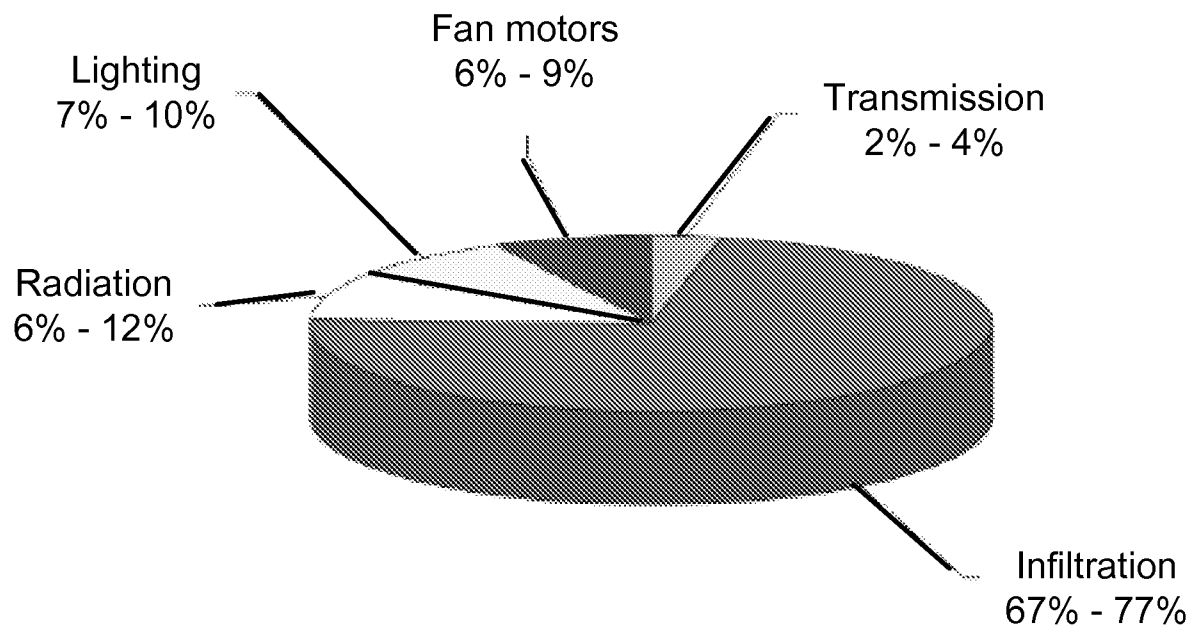


FIG. 10

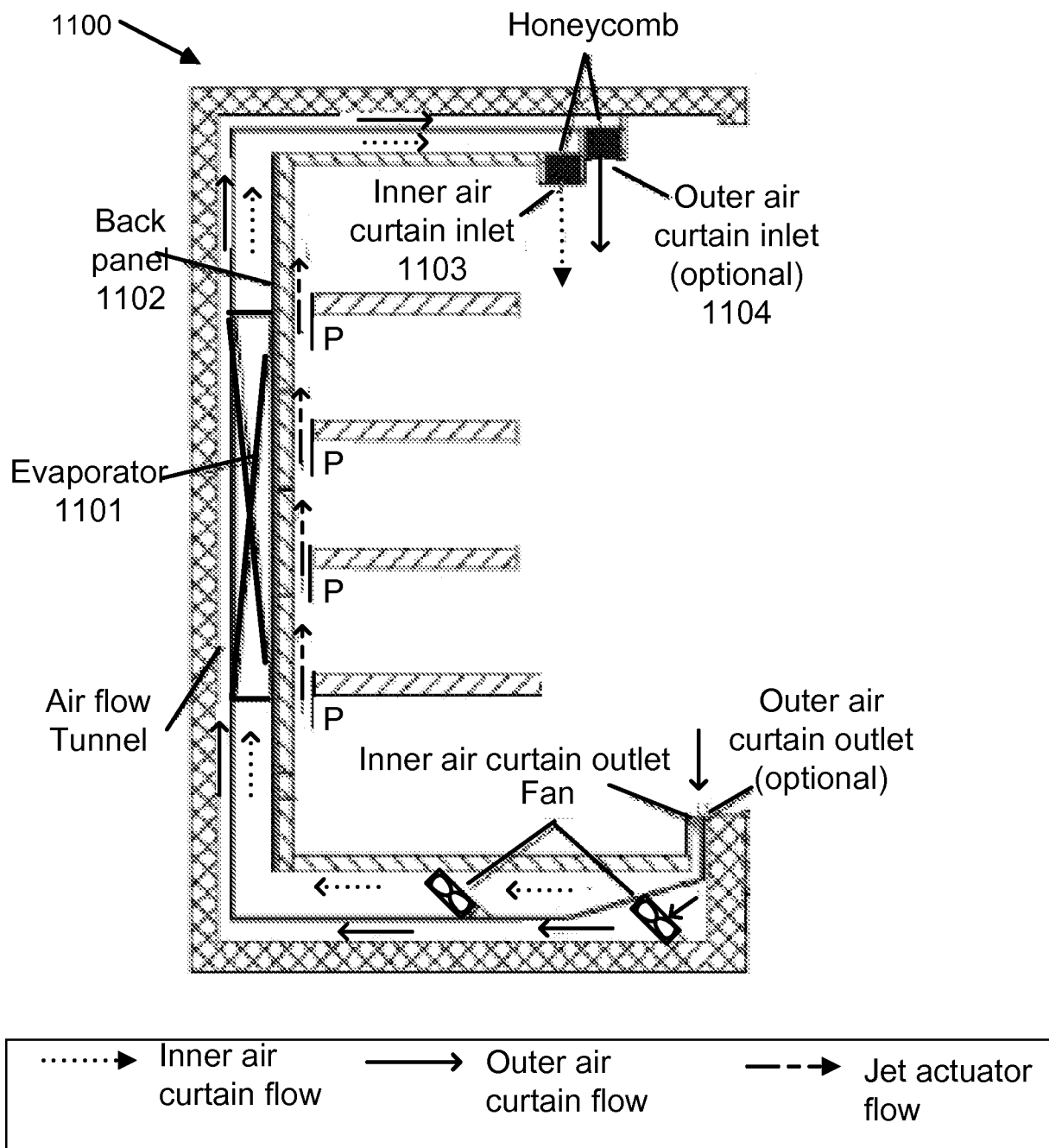


FIG. 11

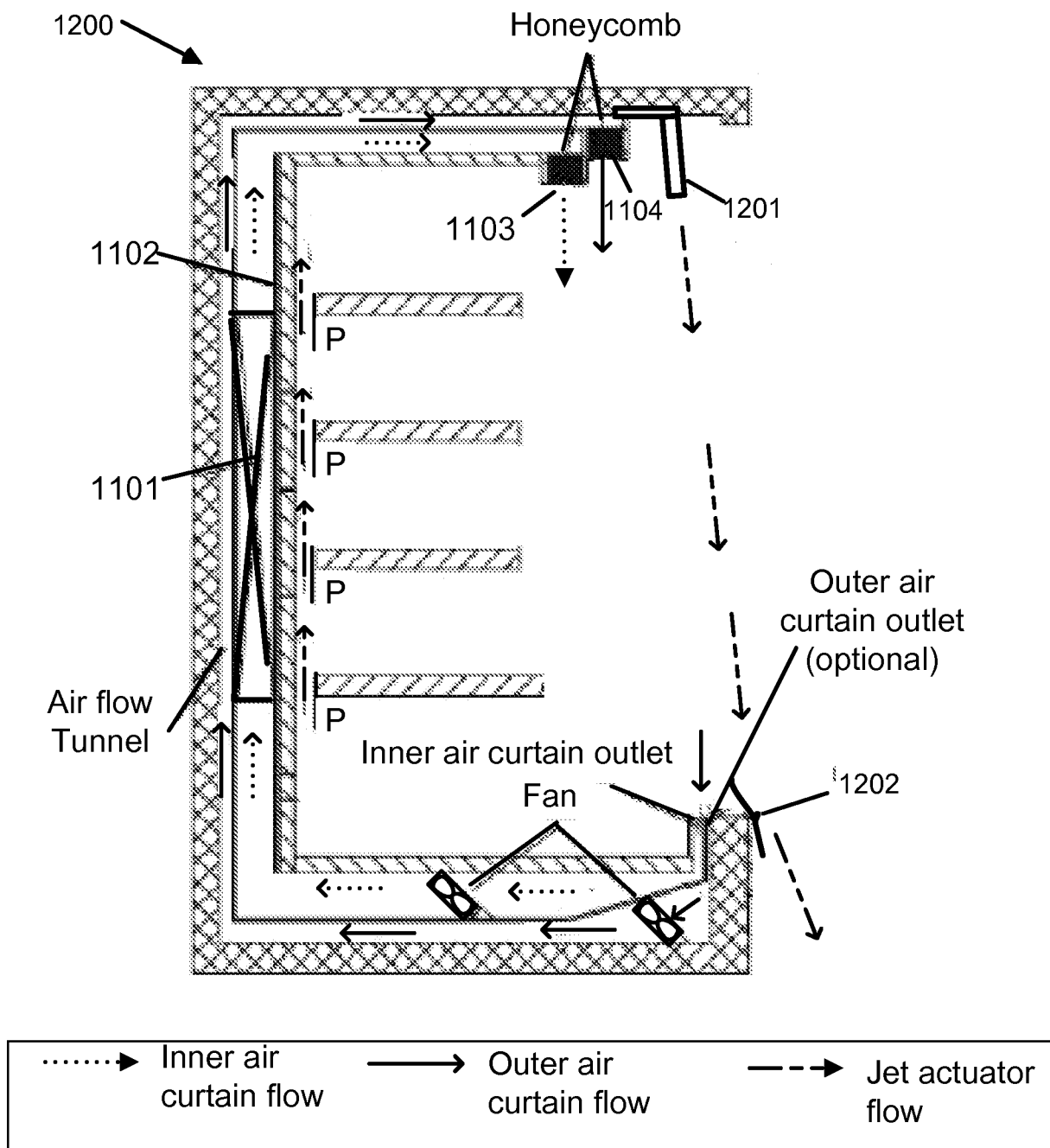


FIG. 12

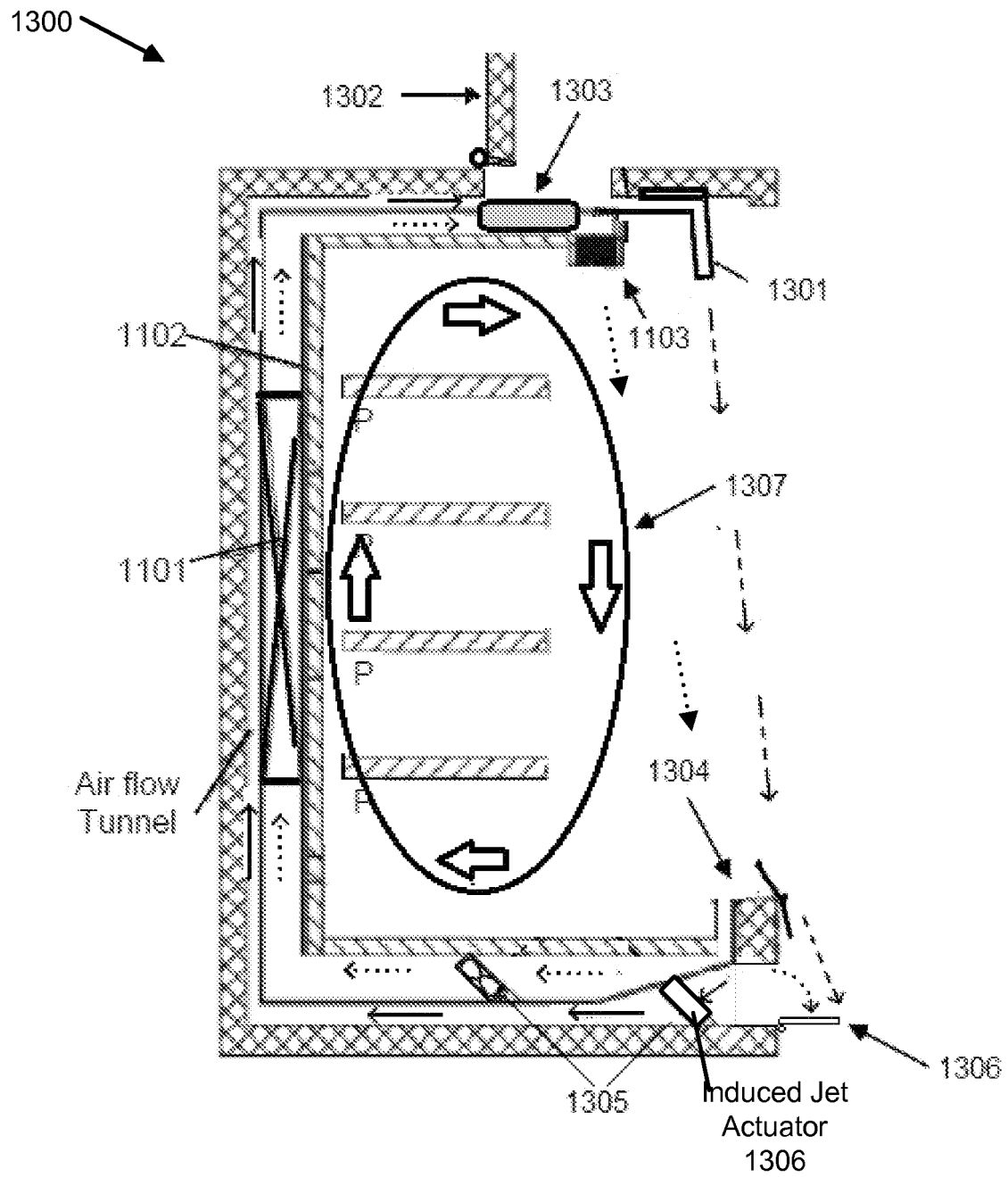


FIG. 13

## INTERNATIONAL SEARCH REPORT

International Application  
PCT/US2014/049411

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A47F 3/04 (2014.01)

CPC - A47F 3/0447 (2014.10)

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)

IPC(8) - A47F 3/04; F24F 9/00 (2014.01)

CPC - A47F 3/0447; F25D 25/028 (2014.10) (Keyword delimited)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
USPC - 62/256, 272; 426/All subclasses; 454/193

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Google Patents, Google.

Search terms used: retrofit, pulse, plasma, jet, actuator, induced, air curtain, display case, refrigerator, cool flow dynamics

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
| X         | US 2009/0215381 A1 (SWOFFORD) 27 August 2009 (27.08.2009) entire document          | 1,5,7-14              |
| Y         |                                                                                    | 2-4,6,15-18           |
| X         | US 2010/0120351 A1 (MORRIS et al) 13 May 2010 (13.05.2010) entire document         | 19-21,23              |
| Y         |                                                                                    | 6,18,22               |
| X         | US 7,681,409 B2 (ALAHYARI et al) 23 March 2010 (23.03.2010) entire document        | 24-32                 |
| Y         |                                                                                    | 15-17                 |
| Y         | US 2010/0329838 A1 (GREENBLATT) 30 December 2010 (30.12.2010) entire document      | 2,3,22                |
| Y         | US 5,368,452 A (JOHNSON et al) 29 November 1994 (29.11.1994) entire document       | 4                     |
| Y         | US 8,226,899 B2 (WOODBIDGE) 24 July 2012 (24.07.2012) entire document              | 16,17                 |
| A         | US 3,134,243 A (HAGEN et al) 26 May 1964 (16.05.1964) entire document              | 1-32                  |
| A         | US 7,497,770 B2 (GRASSMUCK et al) 03 March 2009 (03.03.2009) entire document       | 1-32                  |
| A         | US 6,874,331 B2 (CHANDLER et al) 05 April 2005 (05.04.2005) entire document        | 1-32                  |

☐ Further documents are listed in the continuation of Box C.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

27 October 2014

Date of mailing of the international search report

28 NOV 2014

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774